Landscape Carbon Sampling and Biogeochemical Modeling

A two-week skills development workshop conducted in Senegal

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Summary

The depletion of natural and agricultural resources due to continuous land management in Africa results in reduced crop and livestock production, food insecurity, and the subsequent inability to invest in land improvement. This situation is expressed as widespread rural poverty and environmental degradation that is best mitigated by restoration of organic resources available to affected stakeholders. A net increase in total system carbon (C) accompanies the improvement in organic resource availability, but this relationship is poorly understood because land management is seldom viewed from the perspective of carbon accounting. A confluence of interest exists between the need of land managers to increase the availability of organic resources in degrading lands and the need of society as a whole to mitigate changes in the earth's atmosphere and climate, but this relationship is not well understood and cannot be translated into estimates of carbon sequestration.

A two-week training workshop titled "*Landscape Carbon Sampling and Biogeochemical Modeling*" was hosted by the *Centre de Suivi Ecologique* (CSE) in Dakar, Senegal. The purpose of the workshop was to advance skills in documenting carbon pools and fluxes through field measurement, remote sensing and computer simulation, and to establish a setting where representatives of Senegalese organizations may prioritize research approaches relating to carbon dynamics. The workshop was funded through grants from U.S. Agency for International Development (USAID), The U.S. National Science Foundation and The Rockefeller Foundation. It was attended by 27 participants; 13 from Senegal, 10 from the U.S., and 4 from Kenya. The workshop consisted of three major sections, instruction in the use of the CENTURY Model, field methods of C estimation, and synthesis/planning sessions for future activities.

While gaining experience with the CENTURY Model, participants developed simulations for land management scenarios in Podor, Bambey, Kaffrine, and Velingara in Senegal, and for two sites in the Kenyan Central Highlands, Kabete and Kariti. The files generated through this activity were distributed among participants and represent an excellent opportunity for further efforts involving the calibration and validation of simulations and field data in the future. In combination with the C sampling exercises the preliminary studies suggest: 1.) conversion to agriculture resulted in large losses of biomass and soil organic matter carbon and a spatial redistribution of carbon stocks, 2.) significant carbon stocks still remain in southern Senegal, 3.) farm yields are significantly below potential due to resource limitations, mainly inorganic nutrients, 4.) increased fertilization increases yields substantially but has only a minor impact on the reaccumulation of soil carbon, 5.) the potential to sequester carbon is large but will require major management changes including specific agroforestry applications and some return to long-term fallow, 6.) natural resource management interventions can improve soil carbon and agricultural sustainability but will need to be accomplished with full small holder participation.

Skills in C estimation were developed through field practice in and near the *Institut Senegalais de Recherche Agricole* station in Bambey (ISRA-Bambey). Estimation of total system C was based upon summation of the woody biomass, understorey, surface litter, roots, and soil C pools and was conducted in a natural savanna and a cultivated parkland. Standard quadrat methods for the latter pools were deemed suitable, but the isolated, irregular distribution of parkland trees necessitated the modification of field procedures developed in more humid environments by increasing the tree sampling area. A village tour and discussions were arranged so that participants might better appreciate the concerns of local land manager. In addition to field work, presentations were made on the use of maps, aerial photographs, and satellite images, the calibration of remotely-sensed and ground-truthed data, and in the chemical analyses and physical fractionation of soil C pools.

Plenary and working group discussions led to a workshop synthesis that identified stakeholder constraints to organic resource availability and possible technical interventions and their likely affects on system C stocks. Working groups reported on policy issues affecting C sequestration, established more effective modes of research collaboration among participating institutes, and prioritized the "best-bet" technologies and tree species.

The gains from this workshop should be formalized through the development and award of a collaborative research project designed to better understand the carbon offsets achievable through improved management of Senegal's natural and agricultural resources. Individual scientists must be expected to draft those portions of the proposal in which they will later be involved, rather than merely be contracted to participate at a later stage of project development. This collaborative proposal should be developed during 2001 for funding in 2002 or momentum gained from the workshop will be placed at risk. Whenever possible, research equipment used in training should be available in the host country for further use by national scientists. A mechanism should be found to incorporate expertise in formal C offset projects as required in the future when researchers are confident that realistic C offset targets are identified and if Senegalese policy makers decide that such projects are in their country's best interest.

Introduction

Global concerns over atmospheric change and carbon imbalances are not necessarily reflected in the research capacities of national research organizations in Africa. Carbon debate was initially viewed as peripheral to the more immediate concerns of food insecurity and rural poverty and some policy makers perceived carbon emissions and offset a problem of developed countries (Trexler, 1993). Over the next several years, soil fertility depletion in Africa (Smaling *et al*., 1993) became recognized as the underlying cause of chronically low agricultural productivity and a call was made for strategies for nutrient replenishment (Sanchez *et al*., 1997). Woomer *et al*. (1998, 2000) related nutrient decline to the depletion of available organic resources, noting that a confluence of interest exists between land managers and society-at-large with regard to the reaccumulation of organic resources within farming systems as their increase may accrue carbon in both biomass and soil. Meanwhile, environmentalists from Africa joined ongoing international treaty negotiations related to biodiversity, desertification, and climate change as the consequences of global warming became more apparent and opportunities for carbon trading appeared more tangible. These developments were seldom reflected within national agricultural research organizations as skills in estimating agroecosystem carbon balances remained poorly developed.

The Kyoto Protocol proposed that developing nations could receive “greenhouse gas credits” for increasing soil C stocks as a flexibility mechanism. Model results and observations have shown that some types of agriculture and other land use practices can significantly affect soil C levels. Agriculture that involves conventional tillage and removal of plant material mines the soil of C and nitrogen (N) and can lead to reductions in soil organic matter (SOM) of 50% or more after 50 years of cropping. As soils become depleted of SOM, water holding capacity and nutrient availability decrease, resulting in reduced crop yields. Additions of fertilizer, organic matter, reduced tillage, and N fixing trees, crops, and grasses can lead to increased C in SOM depleted soils and maintain soil C in SOM saturated soils. Reversion to native vegetation can also increase SOM, but this option is of limited applicability given increasing human population. Finer textured soils have a greater capacity to sequester C than coarse textured soils and require more time to deplete SOM.

This report, and the skills development workshop it summarizes, results from an ongoing, collaborative project, Sequestration of Carbon in Soil Organic Matter (SOCSOM) between the USGS/EROS Data Center (USA) and the *Centre du Suivi Ecologique* (CSE) (Senegal). This project assesses the twin roles of soil organic matter in the improvement of agricultural productivity and the sequestration of carbon. African countries sense an opportunity to advance land restoration goals through international initiatives such as the Clean Development Mechanism and the Convention to Combat Desertification and recognize the potential economic and environmental significance of climate change mitigation. In many cases, there is a lack of experience in conducting carbon studies in their fullest, multi-disciplinary context and the SOCSOM project seeks to assist in building that capacity in Senegal, and elsewhere in Africa.

An earlier activity of the SOCSOM Project convened a conference in Senegal on "Carbon Sequestration in Soils" (Dakar, 25 to 27 September 2000). At this meeting a series of presentations were made that established the current state of the arts in carbon studies in Senegal and, to a lesser extent, West Africa (CSE, 2000). During this conference it was established that Senegal seeks to incorporate C sequestration into its ongoing land restoration programs and is careful that its goals of poverty alleviation and increased agricultural production are not to be compromised in pursuit of achieving C offsets. Technical presentations suggested that Senegal has sufficient research facilities to undertake C studies from a systems context, but little

Photograph 1. Participants at the Dakar C dynamics workshop. *Front row, left to right:* Steve del Grosso, Karim Dieye, Petra Tschakert, Dennis Ojima, Modou Sene, Mamadou Khouma. *Top row, left to right*: Paul Bartel, Madeleine Diouf, Ahmadou Beye, Bill Parton, John Lekasi, Magatte Ba, George Ayaga, James Kinyangi, Eric Wood, Rokhaya Diene, Assize Toure and Larry Tieszen. Some participants are absent (Photograph by P.L. Woomer).

experience in doing so. During the conference, a need for training was expressed in the areas of C field measurement and in the use of C dynamics models, which in turn led to the organization of the "Landscape Carbon Sampling and Biogeochemical Modeling Workshop". This report summarizes the events and concluding discussions of that workshop. The overall objectives of SOCSOM and the Senegal Carbon Measurement and Modeling Workshop were to: 1) train scientists from Africa and the U.S. about the current techniques for measuring carbon in ecosystems, 2) train U.S. and African scientists to use models as tools for estimating carbon sequestration in natural and managed ecosystems, 3) evaluate the land use management practices that have potential to store carbon in Senegal and similar regions in the Sahel, 4) consider the social-economic implications of management practices intended to sequester carbon in ecosystems, and 5) promote scientific exchange and carbon sequestration research among U.S. and African scientists.

Venue, Participants, and Program. A two-week training workshop was hosted by CSE in Dakar, Senegal. The workshop was attended by 27 participants, 13 from Senegal, 10 from the U.S., and four from Kenya (Appendix 1 and Photograph 1). Six of those in attendance may be considered as strictly resource persons with specific instructional responsibilities and the others were trainees, although many trainees also provided planned lectures and presentations. The workshop consisted of three major sections: training in the use of the CENTURY Model (5 days), field methods of C estimation (3.5 days), and synthesis/planning sessions for future activities (1.5 days, see Appendix 2). Lectures and computer training were conducted at CSE and field training was held in and around the ISRA station in Bambey. Bambey is located approximately 120 km to the east of Dakar in the densely settled "Groundnut Basin."

Sponsors. The skills development workshop was organized as a component of the SOCSOM Project, which is funded through a grant to the USGS/EROS Data Center by the U.S. Agency for International Development (USAID). Additional donors also contributed to specific areas of the workshop. The U.S. National Science Foundation (NSF) provided a grant to the Natural Resource Ecology Laboratory (NREL) of Colorado State University (CSU) allowing the participation of several resource persons at the workshop, particularly those providing instruction in the use of the CENTURY Model. The Rockefeller Foundation (RF) provided a grant to UNESCO's Tropical Soil Biology and Fertility Programme permitting the participation by young scientists from Kenya. The World Federation of Scientists (WFS) provided support that planned the SOCSOM project. Support from USAID, NSF, and RF is gratefully acknowledged.

Carbon Dynamics Modeling with CENTURY

CENTURY Model Description. The CENTURY ecosystem model was used to investigate how land use and climate affect SOM and plant growth. CENTURY uses inputs of precipitation, maximum/minimum temperature, soil type, and current as well as historical land use information to simulate changes in C, N, crop yields, and other ecosystem parameters. The ability of CENTURY to accurately simulate exchanges of C and N between the atmosphere and soil has been demonstrated by comparing model simulations with data from various natural and managed systems.

CENTURY (Figure 1) includes sub models for plant growth, decomposition of dead plant material and SOM, and soil water and temperature dynamics. Plant growth is limited by soil water content, temperature, and nutrient availability. Carbon and nutrients are allocated among leaf, woody, and root biomass based on vegetation type and nutrient availability. Transfer of C and nutrients from dead plant material to the soil organic matter and available nutrient pools is controlled by the lignin concentration and C:N ratio of the material, abiotic temperature/soil water decomposition factors, and soil physical properties related to texture. Detrital material with low C:N ratios and low proportions of lignin (metabolic) goes to the active SOM pool. The active SOM pool has a rapid turnover time (0.5-1yr) and includes microbial biomass and the highly labile by-products of microbial metabolism. Structural detritus, characterized by high C:N ratios and high lignin contents, flows to the slow SOM pool. The slow SOM pool has intermediate turnover rates (10-50 yrs) and includes the microbial by-products that are moderately resistant to further decomposition. Products of SOM decomposition that are extremely resistant to further breakdown make up the passive SOM pool, which has very slow turnover (1000-5000 yrs). A lower proportion of decomposing SOM is respired as CO_2 and more organic matter is retained in stable forms due to chemical and physical protection as soils become finer textured. The available nutrient pool (NO_3^-, NH_4^+, P, S) is supplied by decomposition of SOM, biological N fixation, and external nutrient additions such as fertilization and N deposition. The proportions of SOM in the respective pools, and soil water, temperature, and texture determine the rate of nutrient supply from decomposition. Available nutrients are distributed among soil layers by assuming that the concentrations of mineral N and SOM are highest near the soil surface and drop exponentially with depth. A detailed description of the SOM model used in CENTURY can be found in Parton et al. (1993) and Parton et al. (1994).

CENTURY can simulate the growth of various crops, grasses and trees. However, only one type of grass (or crop) and one type of tree can be simulated at a time, along with competition between the grass/crop and trees. Different crop, grass and forest systems are distinguished by varying the parameters that control maximum growth rate, C allocation among plant parts and the C:N ratios of plant parts. The model also simulates disturbance events such as burning, grazing and plowing, as well as addition of water and nutrients via irrigation, fertilization, organic matter application, N deposition and N fixation. For a given grass/crop, forest, or savanna (tree and grass) system, plant production is controlled by a maximum plant growth parameter, nutrient availability, and 0-1 multipliers that reflect shading, water, and temperature stress. Parameters in the equations that account for shading, water and temperature limitation, maximum plant growth rate, ranges of C:N ratios for plant compartments, etc. can be adjusted to reflect the physiological properties of various vegetation types and particular species of grasses, crops, or trees. Biomass can be removed or transferred to the litter pool by disturbance events such as harvesting, grazing, plowing, burning, clear cutting, etc. Disturbance events affect both the quantity and nutrient concentration of litter that supplies the SOM pool. For example, fire volatilizes some C and nutrients from the live biomass and litter pools but the ash provides a nutrient rich soil input.

Strategy and Approach. The first week of the workshop was dedicated to training scientists to use the CENTURY plant-soil ecosystem model and demonstrating applications of the model as a tool for estimating carbon sequestration rates from different management practices. During the first two days, we presented a detailed scientific description of the CENTURY model, demonstrated how the model has been used and tested during the last 15 years, and started to get the scientists working with the CENTURY model. The remainder of the week was dedicated to instructing African and U.S. scientists how to use the CENTURY model and evaluate the potential to store carbon in natural and managed ecosystems. The scientists were divided up into groups that focused on evaluating different carbon sequestration strategies for three different sites in Senegal (Bambey, Kaffrine and Podor), and several sites in Kenya and using the CENTURY model to evaluate the impacts of the different carbon sequestration strategies. At the end of the first week, the different teams presented a description of their best bet carbon sequestration scenarios and the estimates of carbon that could be stored, based on the CENTURY model results. A detailed description of the results from the Podor, Bambey, and Kenya working groups are part of this report.

W. J. Parton and D.S. Ojima, the primary architects of this model, and S. del Grosso compiled Senegalese climate data, provided French and English workbooks, and developed preliminary Site100 and Event100 files for refinement during the workshop. The local organizer provided 11 computers for use in training. Many resource persons used laptop computers and LCD monitors to provide instruction on the CENTURY Model. The CSU team also provided several relevant publications to workshop participants (Parton *et al*., 1993, 1994a, 1994b and 2001; Woomer *et al*., 1998). The CSU team brought copies of CENTURY Model as CDs for distribution to all participants.

W. J. Parton introduced participants to the major routines (Figure 1) and sub-routines, primarily as overhead transparency flow diagrams in a lecture during which comments and questions were invited at any time (2 hours). D.S. Ojima then provided elaboration on the sub-routines related to scheduling land management (0.5 hour).

After lunch, participants assembled in the computer laboratory where running the model and constructing its files was demonstrated. (0.5 hour) Participants then received hands-on instruction in running a simulation of Bambey, in the Groundnut Basin using the CENTURY Model (2 hours). Trainees worked as 9 teams of two with four model experts for personal instruction. By the end of the first day, participants had received over 5 hours of training in the use of the CENTURY Model and management of its output.

File100 and Event100 Skills. The second day of training focused upon the files that adapt the model to a given environment and management. Again, the Bambey Site100 file was used, but this time using the long-term monthly climate data with the Event100 files that schedule the sequence of land management developed as a group activity. The site was run as a woody savanna for about 1000 years, converted to agriculture, managed as a fallow rotation, and then continuously cultivated as sorghum and millet until land productivity and system C stocks were severely depleted (3 hours). By the end of the second day, trainees were able to modify site, crop and input management files in File100, and to arrange these into different land management practices through the event scheduler (Event100).

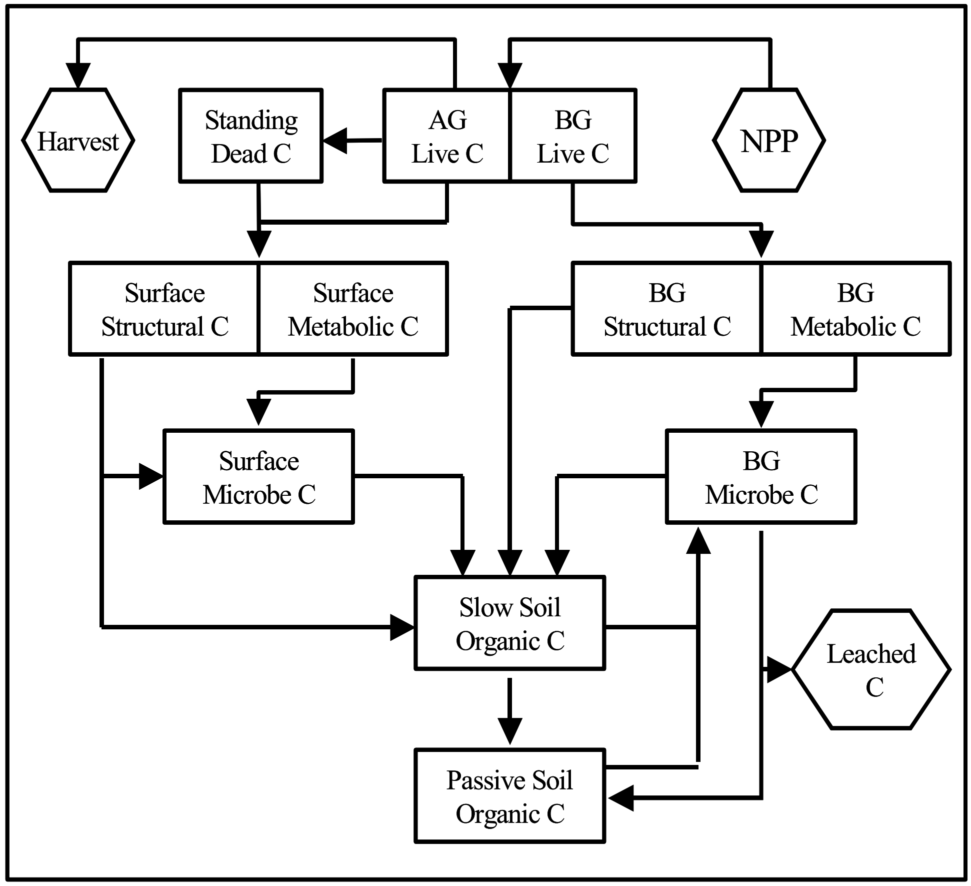


Figure 1. Simplified diagram of the Century Model carbon routines. C inputs result from plant primary productivity, later becoming standing dead or above- or below-ground litter. There are three soil C pools, active (microbial), slow and passive, based upon increasing residence time in soils. C losses occur as harvest removal, leaching or respiration (not included in diagram).

Trainees were then provided opportunity to test their new skills that afternoon by scheduling land management changes that reverse land productivity and promote carbon decline in Bambey. Several interventions were considered by participants including use of improved varieties, crop rotation, improved fallows, mineral fertilizers and mixtures of organic inputs (2 hours). At the end of the session, an impromptu "contest" was held during the brief presentations by participants to determine which proposed management system resulted in the greatest recovery of crop yield and soil carbon. Participants noted that large improvements in crop yield do not necessarily lead to greater soil C storage, and vice versa.

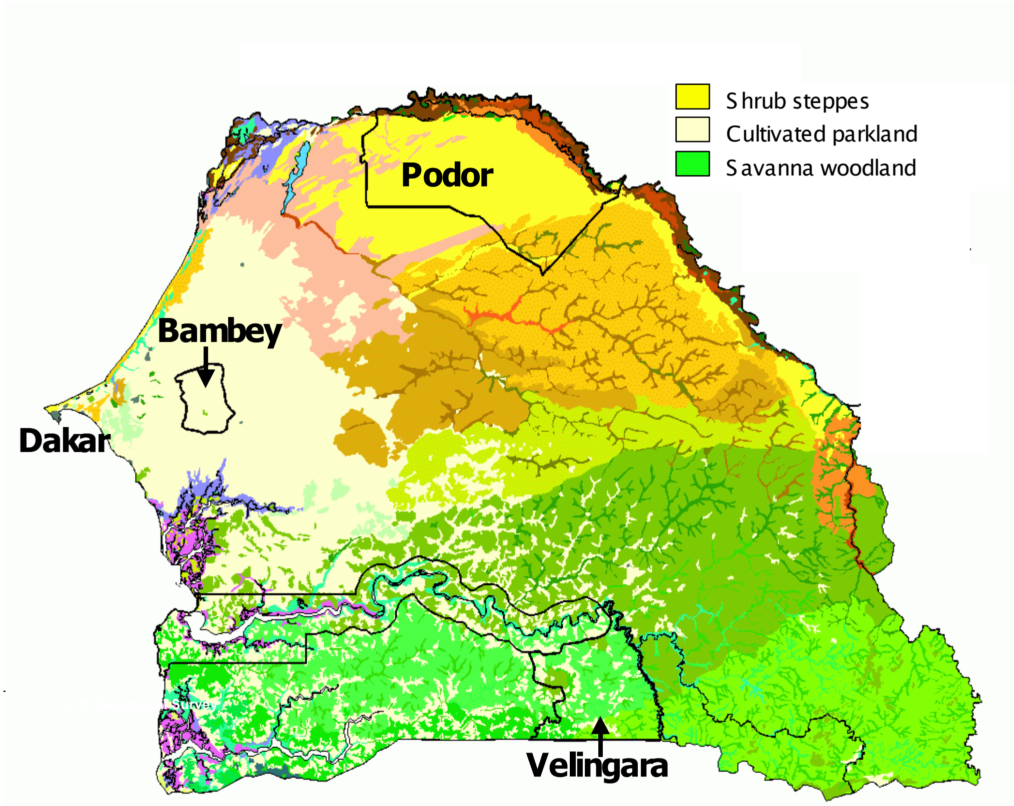


Figure 2. A map of Senegal indicating the three areas and agro-ecological zones identified for carbon characterization and modeling with Century.

Preliminary Site Simulations. For the next two and a half days, participants worked within six teams. Each team focused its attention on a different site (Figure 2), including Podor, Bambey, Kaffrine and Velingara in Senegal, depending on their particular interests and experience. As listed, these four sites comprise a north-south transect that spans the agro-climatic zones of the country. In addition, the three Kenyan participants worked on two sites in the Central Highlands, Kabete and Kariti. Kabete is the site of a long-term soil management experiment. Kariti is densely populated by smallholders practicing maize-based cropping.

Teams presented their simulations with assessments of system carbon stocks. The Podor group focused upon livestock and human activities as drivers of desertification (Figure 3). The Bambey group examined agronomic improvements to cultivated parkland, including greater use of organic fertilizers and nitrogen-fixing legumes (Figure 4). The Kaffrine team reported on the use of improved fallows to maintain crop yields and sequester soil carbon. The possible impacts of different forest management practices on different carbon pools were the main focus of the Velingara team. The Kenyan participants developed eight schedule files representing the treatments in a 2^3 complete factorial, long-term soil management experiment at Kabete and to develop a historical land management scenario for Kariti (Figure 5).

Senegal Workshop Practice Site Simulations and Interpretations

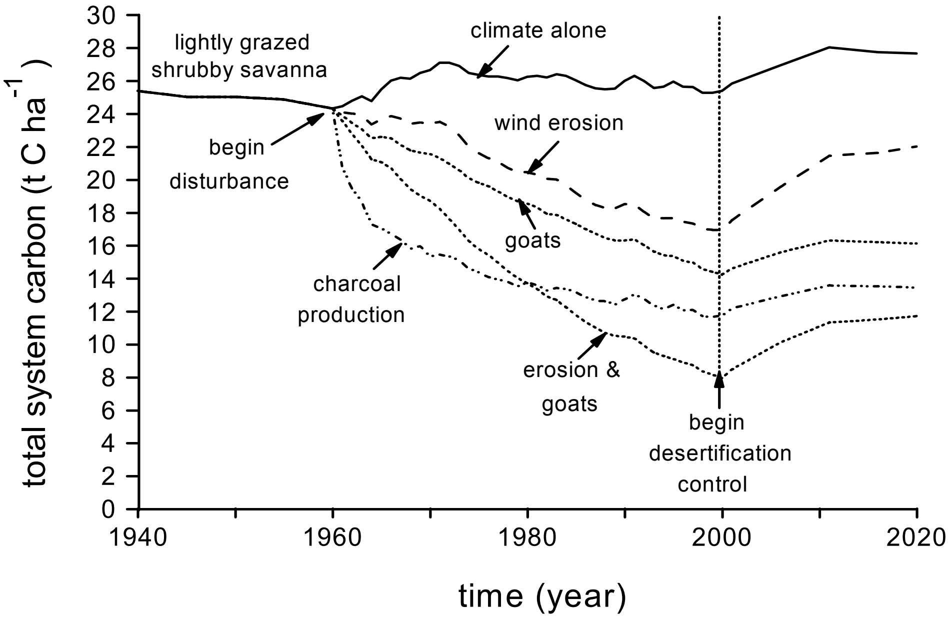
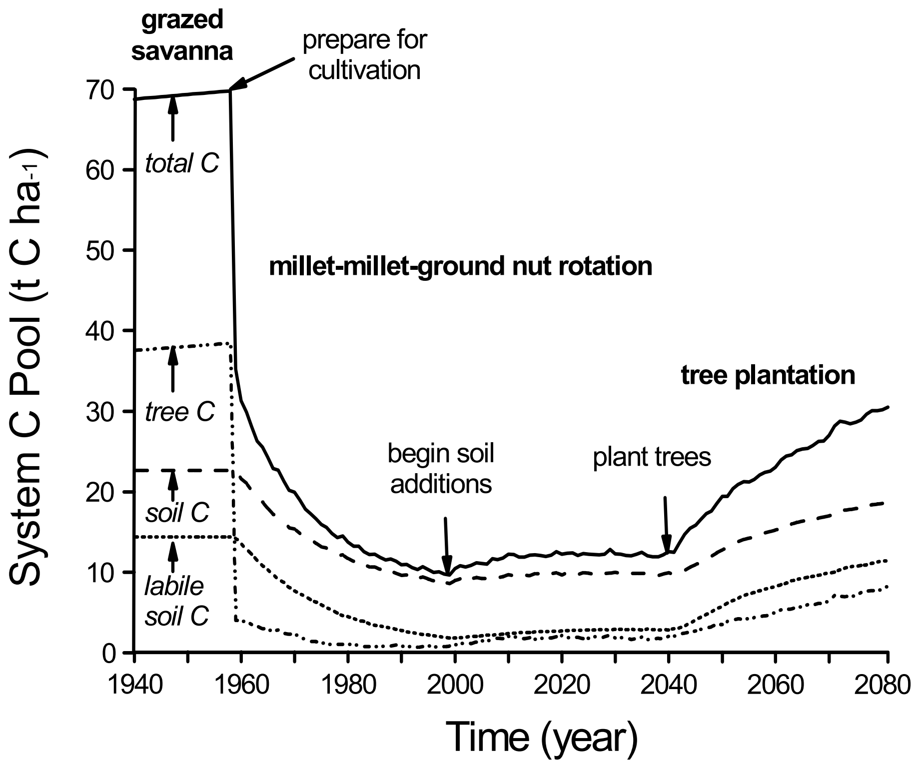


Figure 3. A Century Model simulation of desertification processes in Podor, Senegal. A simulation was developed for a natural, shrubby savanna established on a sandy soil in northern Senegal that is subject to desertification. Several factors believed to be driving desertification including unfavorably dry climate, intense browsing by goats, severe wind erosion (9 t soil ha^{-1} yr^{-1}) and annual collection of wood for charcoal production were examined singly, or in selected combination. A lightly grazed shrub land was simulated for 960 years that equilibrated with approximately 25.6 t C ha^{-1}. Plant biomass, litter and soils (0-20 cm) accounted for 42%, 14% and 44% of the total system C, respectively (data not presented) at the time severe disturbance was initiated in 1960. Simulations using observed monthly climate data between 1960 and 1999 suggested little change in total C stocks due to weather pattern alone. Wind erosion of soil, combined with the climate pattern, resulted in a reduction of total C by 8.2 t C ha-1, with 88% of this loss accounted by changes in soil C (which is likely to be re-deposited elsewhere). Intense monthly browsing by goats, and combination of browsing and wind erosion suggests that total system C is steadily reduced to 14.8 and 8.7 t C ha^{-1}, respectively, after 40 years of disturbance. Wood removal for charcoal collection results in the most rapid system C loss but this effect becomes attenuated as the availability of woody biomass decreases, resulting in an effect that is more severe than wind erosion or goats alone, but less than when these factors are combined. Initiation of a desertification control programme that excludes livestock and human pressures replants N-fixing trees and arrests soil erosion results in immediate but modest C gains, with the 1960 level not obtained for over 100 years (data not presented). It appears more advantageous to protect system C in Podor than to attempt its sequestration following severe disturbance.



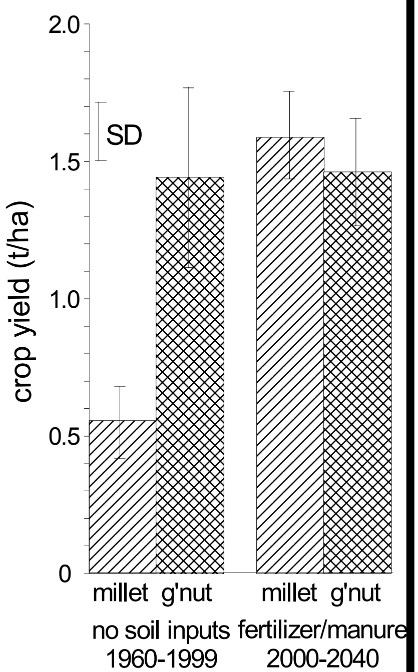


Figure 4. Parkland management in Bambey. A series of *Acacia albida* parkland uses was simulated for Bambey in Senegal's "Groundnut Basin". The lightly grazed woody savanna contains 69 t C ha^{-1} (above), 57% of which is derived from woody biomass. The savanna is then converted to a millet-millet-groundnut rotation for 80 years. As a consequence of conversion to agriculture, 34 t C ha^{-1} is lost as woody biomass. Over the next 40 years, an additional 13 t C ha^{-1} is also lost from the soil, 90% the labile soil C pool. Soil inputs start in 2000, consisting of 1.5 t manure ha^{-1} twice every 3 years and 50 kg N ha^{-1} $crop^{-1}$ applied to millet. This management results in a modest increase of total system C (+2.9 t C ha^{-1}). More substantial recovery occurs over the next 40 years (2040-2080) when the cultivated parkland is converted to a tree plantation (+18 t C ha^{-1}) with 6.3 t C and 9.1 t C ha^{-1} derived from the woody biomass and soil pools, respectively. While improved soil fertility management results in only small increases in system C, it greatly improves yield, particularly for millet (right). Groundnut is less responsive because the simulation assumes that groundnut derives substantial N through symbiosis. This simulation suggests that greater food security may be achieved through better soil fertility management (+890 kg millet), but considerable C offsets require increased woody biomass.

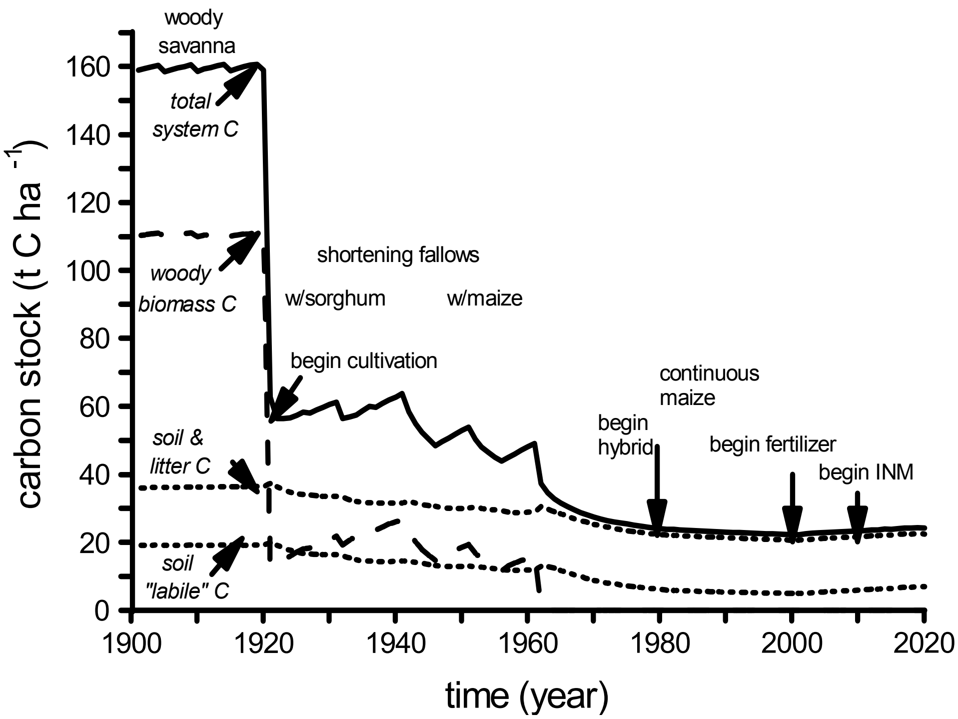


Figure 5. Land use change and carbon stocks in Kariti, Central Kenya. A Century Model simulation was generated to estimate the changes in various carbon pools resulting from land management. Kariti is located approximately 60 km north of Nairobi in the sub-humid Central Kenyan Highlands, contains a loamy clay Nitisol and is densely settled by smallholders practicing maize-based agriculture. First, the simulation was initialized as a lightly grazed woody montane savanna for 920 years, the last 20 years of which appears on the line graph (1900 to 1920). The woodland equilibrates with approximately 160 t C ha^{-1}, 69% of which is woody biomass and 23% is soil C. The woodland is placed into shifting cultivation in 1920 for 40 years, first in sorghum and then maize with shortening fallow intervals. This management reduces system C stocks to about 50-60 t C ha^{-1} with most of the loss occurring from reduced woody biomass. Reduction is soil C (-8 t C ha^{-1}) is largely derived from the "slow" (labile) pool. Continuous maize cultivation commences in 1960 with changes in management reflecting smallholder adoption of hybrid maize (1980) and mineral fertilizers (40 kg N ha^{-1} $crop^{-1}$) from 2000 to 2010 followed by Integrated Nutrient Management (2010 and afterwards). Continuous cultivation results in a further 20 t ha^{-1} decline in total system C as remnant woody biomass removal and labile soil C with almost all system C now contained in the soil. Slight increases in soil C are predicted as a result of adopting Integrated Nutrient Management (INM), a system in which fertilizers are applied to every crop (20 kg N ha^{-1}) and cattle manure (1.5 t ha^{-1}) is applied three out of five years. The carbon stocks resulting from this simulation are in fair agreement with those measured by Woomer *et al*. (1997) except that the Century Model does not consider soil C at depths >20 cm. Additional improvement in total system carbon would likely require adoption of agroforestry practices.

Following the return from fieldwork during the next week, participants were provided a final opportunity to refine their simulations. Their File100 and Event100 files were then shared among participants. The CENTURY training effort was largely successful, in large part because of the strong computer backgrounds of the participants and the relatively high ratio of resource persons to trainees. However, some Senegalese participants admitted to not having suitable computer facilities available to continue their work with the CENTURY Model upon return to their home institutes.

Realistic Site Simulations. CENTURY simulated historical and current SOM levels and projected future SOM levels and crop yields under different land uses. Agricultural systems near Podor (ppt = 22.4 cm), Bambey (ppt = 50.5 cm), Kaffrine (ppt = 58.8 cm), and Velingara (ppt = 87.7 cm) were chosen for simulations because these regions represent a precipitation gradient. For all of these sites, the SOM and nutrient pools in CENTURY were initialized by simulating at least 350 years of native savanna vegetation. The model simulated a perennial tropical grass and an N-fixing drought deciduous tree. Ground fires affecting primarily the grass were assumed to occur every 5 years, while major fires that burned grass and trees were scheduled to occur every 30 years. Moderate grazing during the rainy season (June - October) was also included in the initialization runs. Beginning in 1850-1960, depending on site, managed agriculture replaced the native savanna system. The past land uses simulated by the model were based on the agricultural practices that were commonly used in the respective regions. Projections into the future included both traditional practices and alternative land uses that may be feasible for these regions. The following paragraphs discuss model simulations and results for Bambey, Kaffrine, and Podor. The results for Velingara are not reported here because reliable information on historical and current land use practices were not available when the simulations were performed.

For each site, we developed site files required by CENTURY, which include parameters for climate, soil physical properties, external nutrient additions, and initial conditions. We also developed CENTURY schedule files for each site that include information describing relevant management and disturbance events (e.g. planting/harvesting, fire/grazing) and their timing. The site files and schedule files used for the simulations of Bambey, Kaffrine, and Podor are available at http://edcsnw3.cr.usgs.gov/ip/carbonseq/workshop2001.html.

For the Bambey site, native savanna was simulated from 1500 to 1850 and a 7-year rotation was implemented from 1851 to 1900. Trees were burned and millet was grown the first year (1851), sorghum the second, and native grass with grazing during years 3 through 7. From 1901 to 1945 a 5-year rotation was simulated. Millet was grown the first year, groundnut the second, sorghum the third, and 2 years of native grass with grazing. Trees were cut or grazed every year. From 1946 to 1965 a similar 4-year rotation was implemented with the only difference being that only 1 year of grass was included. From 1966 to 1981 a 2-year rotation with fertilization was simulated. Groundnut (1 gN m^{-2}) was alternated with millet (2.1 gN m^{-2}). From 1982 to 2001 a 4-year rotation with organic matter addition was simulated. Grass was followed by groundnut and 2 consecutive years of millet. Manure (60g C m^{-2}) was added each year. Tree removal ceased in 1998. From 2002 to 2050 two alternative scenarios were considered. One involved 2-year ground nut/millet rotations with no organic matter or fertilizer additions. The other scenario was a 3-year ground nut/millet/grass rotation. The groundnut was fertilized with 1 gN m^{-2} and the millet was amended with 60 gC m^{-2} of manure and 90 g C m^{-2} of leucaena prunings. The grass was amended with 60 gC m^{-2} of manure and was not grazed.

SOM C showed a sharp decline beginning in 1851 when agriculture was introduced (Figure 6a). By approximately 2000, the SOM approached a new equilibrium as the result of two factors. The SOM pools that were subject to perturbation were largely depleted and fertilizer additions beginning in 1967 increased NPP and helped stabilize SOM. Addition of fertilizer and organic matter beginning in 2002 led to a significant increase in SOM compared to the groundnut/millet rotations with no fertilizer or organic matter additions, although both of these scenarios stored C in soil. Inclusion of a year of native grass with no grazing as part of the rotation with additions contributed to the higher simulated increase in SOM C. The groundnut/millet cropping with no additions stored SOM during 2002-2050 because tree removal ceased in 1998.

Fertilizer and organic matter additions led to higher net primary productivity (NPP) during most, but not all years (Figure 6b). The years when the no addition treatment had higher NPP were all even years when groundnuts were grown. Apparently, the years with higher NPP for the no addition treatment result from an interaction between precipitation and N fixation associated with groundnuts. Figure 6c shows the decline in soil fertility and grain yields as the soil was mined of C and N from 1850 to 1960. Introduction of groundnut in 1902 led to a temporary increase in millet yields, presumably due to increased N fixation. Grain yields reached a minimum in the early 1960's and then showed a sharp increase as a result of N fertilization initiated in 1966. Groundnut growth is relatively immune to poor soil conditions and did not decline as SOM C decreased, in contrast to the millet and sorghum.

Native savanna was simulated from 1500 to 1950 at the Kaffrine site. Trees were cut and burned in 1951. From 1952 to 1975 a 3-year groundnut/millet/grass with grazing rotation was simulated. Trees were controlled with annual burns. The same rotation was continued from 1976 to 2001 except that the groundnut crop was amended with 100 gC m^{-2} of manure and 0.9 gN m^{-2} fertilizer and the millet was amended with 100 gC m^{-2} of manure and 2.1 gN m^{-2} fertilizer. From 2002 to 2050 grass was grown with no grazing and trees were not burned. An alternative scenario for this site included a 5-year rotation from 1982-2050. Groundnut (100 gC m^{-2} and 0.9 gN m^{-2}) and millet (100 gC m^{-2} and 2.1 gN m^{-2}) with organic matter and fertilizer additions were followed by grass with grazing and a cassava crop. The cassava was planted in August of the 4^{th} year and harvested in February of the 5^{th} year. Trees were controlled by burning.

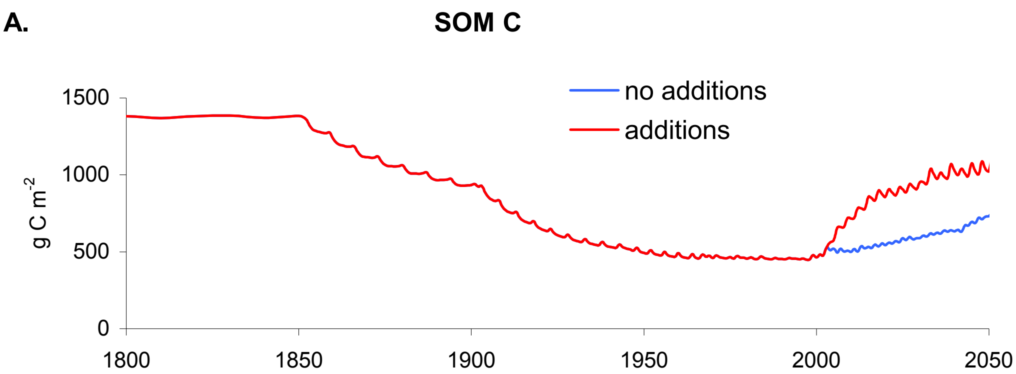
Similar to the Bambey site, the Kaffrine simulations showed a sharp decrease in SOM C initiated when trees were burned and the land was cropped (Figure 7a). There was a small increase in SOM C beginning in 1976 when fertilization and organic matter addition was initiated. Reversion to grass and trees with no burning led to significant SOM C gains beginning in 2002. The crop rotation continued to produce a loss in SOM C even though fertilizer and manure were added to the groundnut and millet crops because the trees were burned and the grass was grazed. Figure 7b shows that most years the non-grazed/non-burned savanna had higher NPP than the crop rotation.

Native savanna was simulated from 1500 to 1960 at the Podor site. Moderate goat grazing of the grass and trees was in effect from 1961 to 2000 and no grazing from 2001 to 2045 for one scenario while heavy goat grazing from 1961 to 2045 was simulated as an alternative scenario. SOM C began increasing in 1960 because of fire suppression and reached another equilibrium in ~1975 (Figure 8a). SOM C began increasing again in 2000 when grazing ceased. Figure 8b compares NPP for grazed and ungrazed treatments. Some years show higher NPP for the ungrazed but most years show little difference between the two treatments. The larger increase in SOM C associated with moderate/no grazing is more a result of more biomass lost to respiration with grazing than a decrease in NPP as a result of grazing.

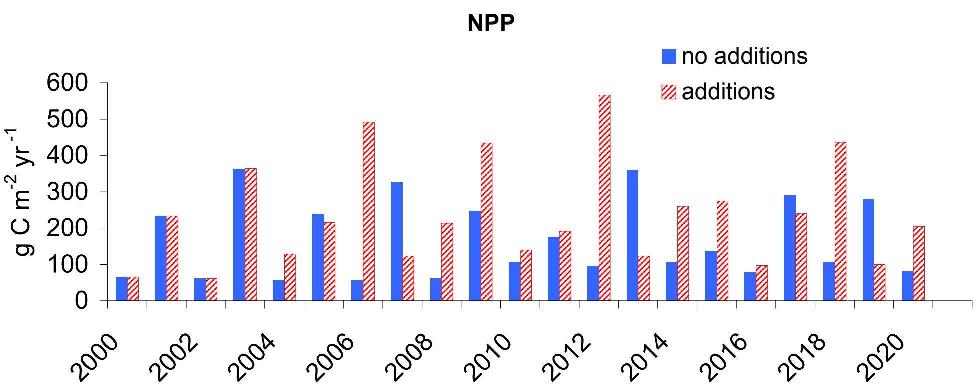
Comparison of figures 6a, 7a, and 8a shows that equilibrium SOM C values are highest in Kaffrine and lowest in Podor. This is a result of differences in plant growth, which is driven by precipitation. Podor is very dry, so plant growth is limited and inputs from dead plant material to the soil C pools are reduced, resulting in very low SOM C levels. Kaffrine has slightly higher precipitation and correspondingly higher SOM C levels than Bambey. The overall results suggest that soils that have been traditionally used for agriculture in Senegal are depleted of SOM C, and that SOM C can be increased by amending the soil with organic matter or fertilizer, fire suppression, and reversion to the native savanna system. However, these coarse textured soils have limited capacity to store large amounts of C unless they are allowed to return to the savanna system with no grazing and fire suppression, which is probably not a likely scenario for most areas. Although these agricultural systems have little potential to store C, crop yields can be significantly increased with fertilizer or organic matter additions and by N fixing crops. Simulations suggest that trees make a significant contribution to SOM C and that fire suppression can increase NPP and soil C storage.

FIGURE 6 SIMULATIONS FOR BAMBEY

A.



B.



C.

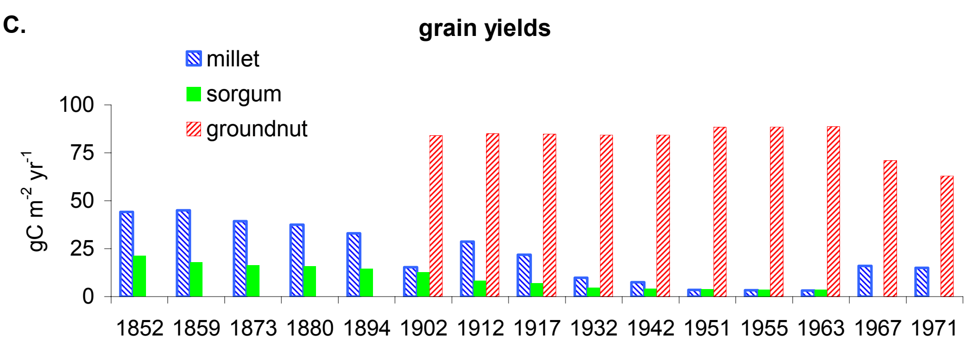
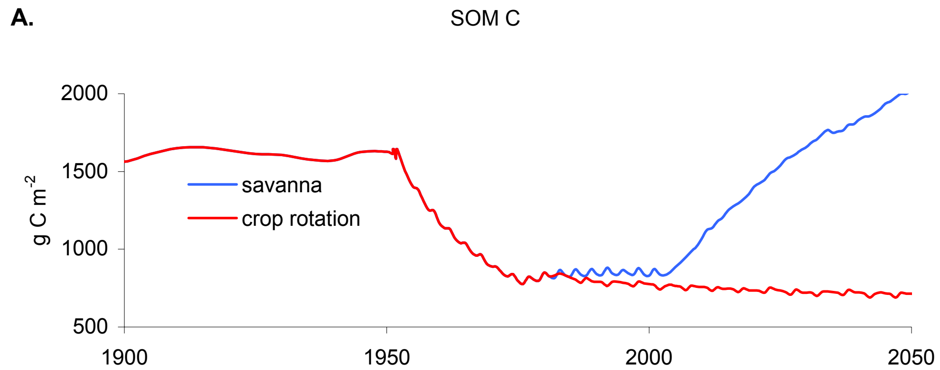
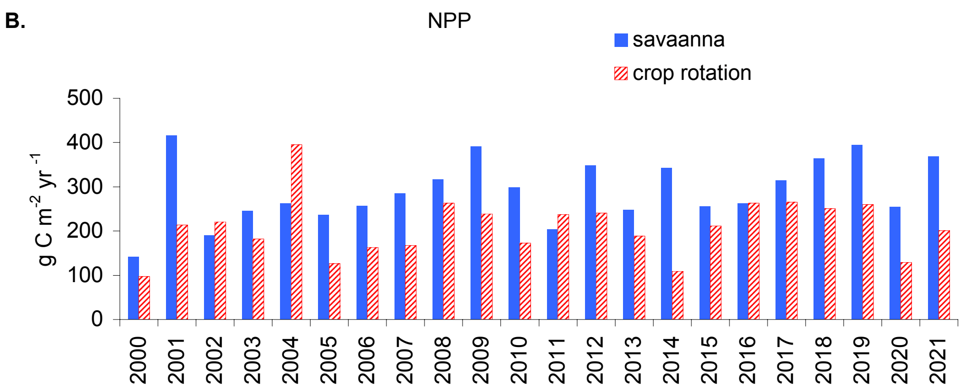


FIGURE 7 SIMULATIONS FOR KAFFRINE





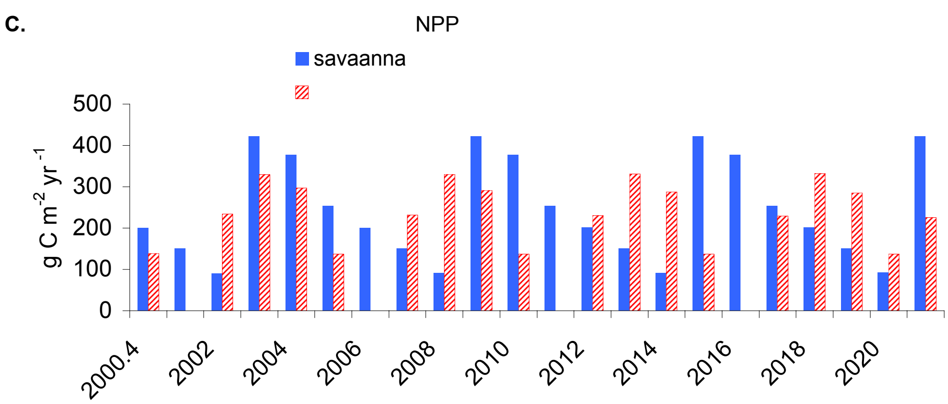
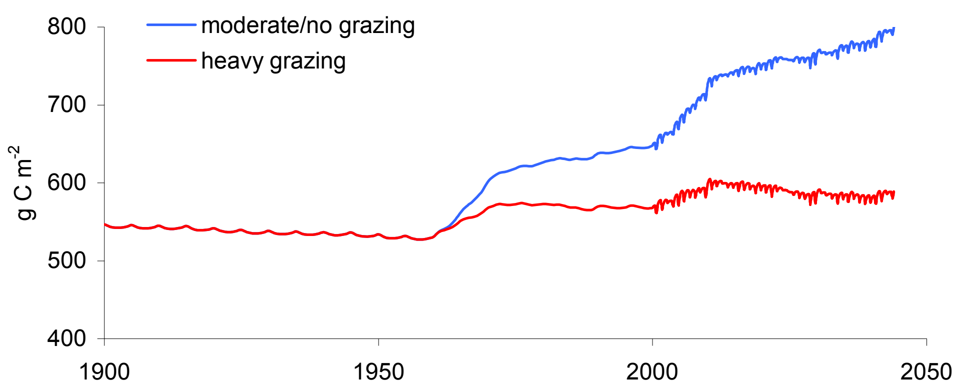
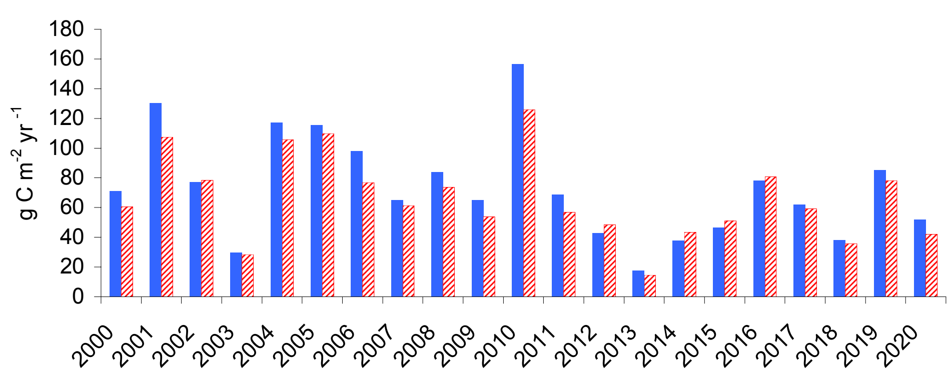


FIGURE 8 SIMULATIONS FOR PODOR

A. **SOM C**



B. **NPP**



Photograph 2. Field tools necessary for the estimation of total system carbon that were provided to scientists from CSE and ISNAR-Bambey.

Carbon Measurement

Instruction for this portion of the workshop was based upon the preparation and distribution of a booklet *Field and Laboratory Guidelines for Carbon Characterization of Vegetation and Soils* (Woomer, 2001) and the assembly and distribution of two complete sets of field tools (Photograph 2). Field practice in estimating system carbon stocks was undertaken on and near the ISRA station in Bambey. Participants traveled from Dakar to Bambey on Friday afternoon, 2 March, and stayed at the ISRA guesthouse. Upon return to Dakar, instruction in data compilation was provided and refinement of field procedures were discussed. The following section on Carbon Measurement should be considered as an amendment to the field guidelines (Woomer, 2001) and those seeking details on field and laboratory

Photograph 3. Understorey and litter sampling during the dry season in a cultivated parkland was a relatively easy task assigned during the first day of fieldwork in Bambey (*left*). Measuring diameter at breast height of woody biomass in a shrubby savanna required that rules be applied with regard to minimum diameter and position with respect to the central transect (*right*).

methods are referred to that booklet. A detailed account of field and data compilation activities during this portion of the workshop follows.

Cultivated parkland. Participants were introduced to the various field tools supplied by Dr. Woomer (see Photograph 2 and Appendix 3) and then practice with those tools was provided at a nearby *Acacia albida* cultivated parkland. Participants were voluntarily separated into two teams and asked to perform the field procedure described in the field manual (Woomer, 2001) accompanying the tools. This site was relatively easy to characterize because it contained few trees and scattered understorey (Photograph 3, *left*).

Each team member was expected to gain experience at site selection and field randomization by performing as the group leader, and in working as a team member in the measurement of woody biomass, understorey and litter biomass and at soil collection, with each of these “C pools” requiring a different set of skills. Based upon this field site, it was decided that the major quadrats and woody biomass transects must be larger than originally planned because of the relatively few, isolated trees remaining in the cultivated fields (Photograph 3, *left*). Dr. D. Slaymaker also demonstrated the field measurement of tree height and canopy area in this setting.

Grazed natural savanna and tree plantations. That afternoon experience was obtained at a much more difficult field site, a grazed woody savanna with mixed shrub and grass understorey (see Photograph 3). A more advanced understanding was developed on selecting woody biomass for diameter measurement because some trees were multi-branched below breast height, and in the systematic selection of clipped understorey biomass originating from outside but falling within the quadrats. Participants gained appreciation that more, shorter sampling transects were appropriate to estimate C stocks in these shrubby savannas. Afterward, the ISRA agroforestry project site was visited and field methods for sampling systematically arrayed fields were demonstrated. In this case, it was emphasized that the requirement for randomization is not waived in tree plantations, but rather must be applied in a manner that allows for representative rows of trees to be sampled at random. The large potential contribution of woody biomass contained in trees planted along field boundaries was also demonstrated.

Village Carbon Resources

The Groundnut Basin is an area of intensively cultivated, village-based agriculture where groundnuts are usually grown in rotation with millet. The climate is semi-arid (400 to 800 mm precipitation yr^{-1}) with rains normally falling between July and September. Soils are sands with low inherent fertility and moisture holding capacity. The natural vegetation was woody savanna, but is now cultivated parkland with widely spaced *Acacia albida* (syn. *Faidherbia albida*) and baobab (*Adansonia digitata*). Groundnut cultivation commenced in the 1920s under French colonial rule and was intensified during the Second World War. Following independence in 1960, groundnut cultivation was supported through government subsidies on fertilizer and seeds, and the establishment of extension and marketing networks. Groundnuts remain an extremely important cash crop to farmers, and an export commodity for Senegal, despite a trend of declining rainfall, periodic drought (1972, 1982-1984, 1996-1997) and withdrawal input subsidies due to structural readjustments in 1984.

Village-based farming systems may be separated into three major components, cultivated parkland outfields, infields, and the villages proper. The outfields are usually devoted to millet-groundnut rotation with crop residues transported toward the village for use as livestock feed, organic inputs to soils, cooking fuel and structural material. During the long dry season, livestock browse the remaining stubble. In general, infields are used for household millet production and occasionally for vegetable production, which may receive an assortment of organic inputs to soils and may occasionally be fenced for protection from grazing livestock or irrigated for year-round production. Petra Tschakert surveyed nine villages near Bambey and Thies in 2000, querying villagers on their cropping practices and addition of soil inputs. Figure 4 illustrates the large number of soil management strategies employed but also suggests that the most frequent are cereal legume rotation, intercropping and parkland agroforestry. Clearly, documentation of C soil dynamics resulting from ongoing organic resource transfers will require that several management options must be considered when sampling strategies are developed. A more detailed description is available at http://edcsnw3.cr.usgs.gov/ip/carbonseq/workshop2001.html.

Participants were first introduced to maps, satellite images and aerial photographs of Senegal and the Bambey area by Gray Tappan and the changes in land use over time as interpreted by these tools was discussed. Emphasis was placed upon the changes within Senegal's "groundnut basin" and the immediate area around Bambey, with emphasis on the sites visited the day before, and Santhiou Lam, the village selected for that day's activities by Petra Tschakert.

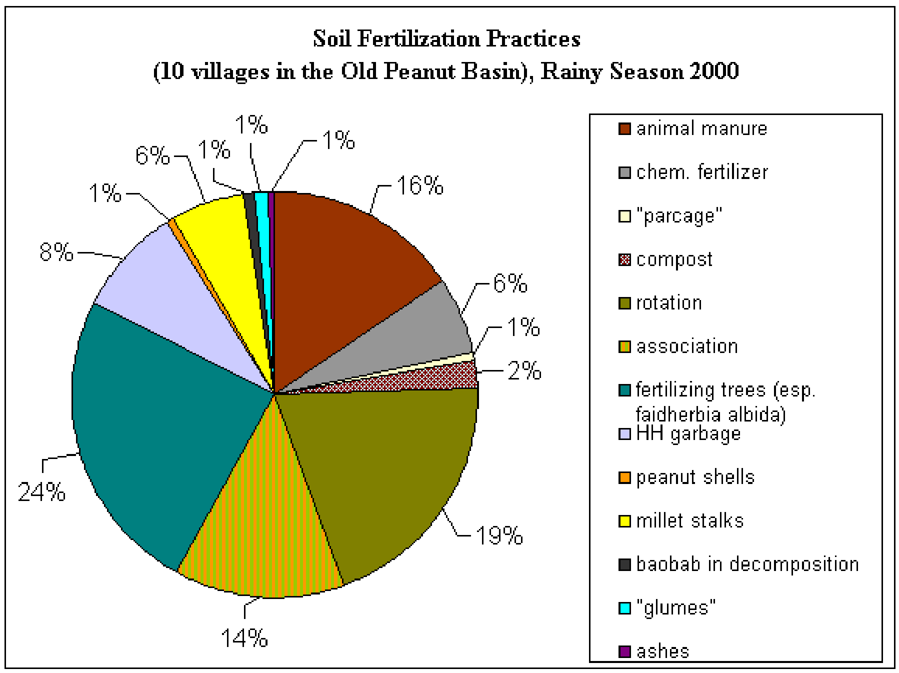


Figure 9. Soil management strategies employed at nine villages of Senegal's groundnut basin (figure provided by P. Tschakert).

Photograph 4. Millet is the major staple of the farmers in Bambey. It is often grown in close association with trees (left) and straw may be uprooted for use as livestock feed and cooking fuel.

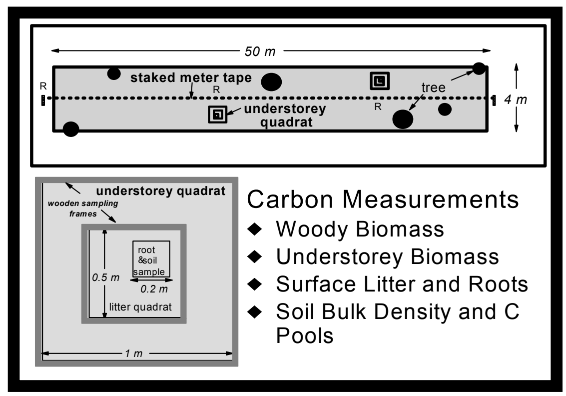
Next the group traveled to Santhiou Lam, which is approximately 12 km to the northeast of Bambey. Santhiou Lam consists of a cluster of households, surrounded by an infield and about 200 ha of cultivated parkland and is run by a village headman who is in turn accountable to an area chief. Land is farmed by individual families on plots assigned by the village headman. Initial discussions were held with villagers who expressed concerns over declining yields and soil fertility, reduced recharge of the >40 m deep village well, striga infestation of millet and insufficient availability of labor during periods of peak demand, particularly for weeding millet and groundnuts. A tour of village fields was conducted by the headman and some villagers to illustrate these points, however, as it was the latter dry season, there was relatively little to see concerning the above points. Several observations were made during the tour that influence C dynamics and agro-productivity:

1. Millet straw (and many roots) appear routinely harvested and stored adjacent to the village for use as livestock feed, cooking fuel and periodically as fences.
2. Organic resources (manure, groundnut pods and millet threshings) are concentrated in the "inner fields" prior to planting.
3. There is insufficient supply of water for market gardening during the dry season.
4. Tree planting is restricted to home compound areas as seedlings are difficult to establish elsewhere due to watering requirements and difficulties in protection from livestock.

5. Two drought-tolerant, annual food legumes that could benefit the farming system are tepary bean (*Phaseolus acutifolius*) and moth bean (*Vigna acontifolia*), two symbiotic N_2-fixing species that occupy important roles in sub-tropical dry land farming systems of N. America and India, respectively, but are little known in Africa.

All of these points bode poorly for poverty alleviation of the villagers and the potential of the outfields to maintain current C stocks or to sequester more C. On the other hand, there is undoubtedly a large (but seemingly unknown) increase in C stocks within and immediately surrounding the village due to redistribution of organic resources and tree planting within individual compounds. Shortly before leaving Santhiou Lam, participants were provided opportunity to practice their skills at rapid estimation of woody biomass using another transect method introduced by Dr. Larry Tieszen, the Point-Quarter Sampling technique, described in fuller detail later. During practice with the Point-Quarter Sampling technique, Dr. D. Slaymaker again provided opportunity for participants to gain experience in use of the inclinometer.

Figure 10. The sampling areas for woody biomass (200 m2), understorey biomass (1 m2) surface litter (0.25 m2) and roots and soil (0.04 m2 to a depth of 40 cm). The major quadrate for woody biomass was observed to be suitable for natural and grazed savannas, but not for cultivated parklands and alternative sampling procedures are presented later in this report.



Field Data Compilation and Synthesis

The purpose of this session was to demonstrate how data collected in Bambey earlier in the workshop is expressed as units of carbon. This skill requires that participants understand the use of conversion factors based upon sampling areas and units of mass, be able to calculate woody biomass by applying allometric equations to field measurements, understand how to identify the appropriateness of sampling procedures and sample areas and how to compile, analyze and interpret carbon measurements.

Conversion factors and sampling areas. Estimation of total system carbon requires that measurements of woody biomass, plant understorey and crops, surface litter, roots and total soil carbon be performed, converted into carbon, placed into identical units (e.g. t C ha^{-1}) and then summed. Different, measurements are preformed within different sampling areas (Figure 10) and hence require the use of different conversion factors before these are expressed into identical units (Table 1). Trees, understorey, fresh litter and washed roots may be assumed to consist of 45% to 50% C, partially decomposed litter that has reacted with soil must be chemical analyzed for total C in the same manner as are soils (see Woomer, 2001). Further explanation of these issues may be obtained from Woomer and Palm (1998).

Carbon stocks are calculated from field data, conversion factors and C contents as:

$$\textbf{C stock (t C ha}^{-1}\textbf{) = mass plot}^{-1}\textbf{ x plot ha}^{-1}\textbf{ x C mass mass}^{-1}$$

And is applied to tree biomass as

$$\textbf{tree C (t C ha}^{-1}\textbf{) = 220 kg tree plot}^{-1}\textbf{ x 50 plot ha}^{-1}\textbf{ x 0.5 kg C kg tree}^{-1}\textbf{ x 0.001 t kg}^{-1}$$
$$\textbf{tree C (t C ha}^{-1}\textbf{) = 5.5 t tree biomass C ha}^{-1}$$

Table 1. Sample areas, conversion factors for different field measurements and example data obtained from the Bambey field practice.

Measurement	Sample area	Conversion factor[a]	Data[b]
tree biomass	200 m^2	x 50	220 kg
understorey biomass	1 m^2	x 10000	45 g
surface littler	0. 25 m^2	x 40000	90 g
root biomass	0.04 m^2	x 250000	16 g
soil organic carbon	0.04 m^2	- na -[c]	0.3%

[a] converts sample area to ha by dividing sample area into 10000. [b] estimated during from field activities at the dry season cultivated parkland in Bambey. [c] not applicable as percentage measurements must first be corrected by soil bulk density.

Applying the same mathematical procedure to measurements of the other biomass and litter stocks estimated for the Bambey cultivated parkland, after converting from g to kg, results in the values: understorey = 0.23 t C; litter = 0.45 and roots = 2.0 t C ha^{-1}. When totaled, these values are 8.18 t of biomass and surface litter C per ha, although readers must be aware that the field data were obtained from incompletely replicated and improperly dried samples that serve better to illustrate data compilation and conversion procedures than to accurately estimate C stocks in the Bambey parkland.

Calculating Soil C. Soil carbon measurements expressed as concentrations must be expressed as mass per unit area using the relationship:

$$\textbf{Soil C mass (g m}^{-2}\textbf{) = soil C (g C g}^{-1}\textbf{) x volume (cm}^{3}\textbf{ m}^{-2}\textbf{) x density (g cm}^{-3}\textbf{)}$$

It is convenient to express soil volume on a m^2 basis to the soil test depth. For example, 1 m^2 to a depth of 20 cm is 100 cm x 100 cm x 20 cm = 200000 cm^3 (Figure 4). This expression of soil volume then becomes consistent with a common dimension for soil bulk density (g cm^{-3}). Percentage C requires transformation to the decimal expression using a factor of 0.01 g g^{-1}. Therefore, the calculation of total soil carbon for 1 m^2 of a soil with 0.4% C to a depth of 20 cm is:

$$\textbf{0.004 g C g}^{-1}\textbf{ soil x 200000 cm}^{3}\textbf{ m}^{-2}\textbf{ x 1.45 g soil cm}^{-3}\textbf{ = 1160 g soil C m}^{-2}$$

It is important to note that these are the dimensions in which soil carbon fractions are expressed in the outputs of the CENTURY Model. Conversion of C from g m^{-2} to t ha^{-1} is then performed by the mathematical operation:

$$\textbf{1160 g soil C m}^{-2}\textbf{ x 10000 m}^{2}\textbf{ ha}^{-1}\textbf{ x 0.000001 t g}^{-1}\textbf{ = 11.6 t soil C ha}^{-1}$$

From the above equation, note that **t ha^{-1} = 0.01 g m^{-2}** or conversely **g m^{-2} = 100 x t ha^{-1}**. When the soil C estimate is combined with the biomass and litter estimates above, the total system C of the cultivated Bambey parkland is estimated to be 19.78 t C ha^{-1}, with 59% of this C residing in the soil (0 to 20 cm).

Use of allometric equations to calculate wood biomass and tree sampling area. Tree biomass was estimated from diameter measurements with the power equation of FAO (1997) for allometrics in moist tropical forests with tree diameters from 5 to 148 cm:

$$\textbf{tree biomass = exp}^{(-2.134 + (2.530 \ln D))} \quad \textbf{(n = 191, r}^{2}\textbf{ = 0.84)}$$

where tree biomass is expressed as kg $tree^{-1}$ and D is the DBH expressed in cm. Tree biomass was converted to carbon by a factor of 0.45. A diskette containing an Excel spreadsheet file based upon the above equation that calculates individual tree biomass from diameter at breast height measurements and sums up to 25 trees per plot was distributed to workshop participants. Participants than entered the tree diameter measurements collected in major quadrats and transects in Bambey into the spreadsheet to calculate woody biomass in their study sites

Alternative allometric equations. Allometric equations applicable within specific dry, moist and wet tropical forests are presented in Brown *et al.* (1989) and FAO (1997). A equations advanced by Brown *et al.* (1989) and others which include a term for tree height was not considered above because this parameter is difficult to estimate in closed canopies. However, given the ease of tree height measurement using an inclinometer in cultivated parklands, the importance of tree height in improving allometric predictions and the role of tree height in ground-based canopy measurements, perhaps equations including tree height should be reconsidered.

Another potentially important equation derived from dry forests in India with annual rainfall of >900 mm yr^{-1} and tree diameters of 5 to 40 cm based on only 28 trees but recommended by FAO (1997) is:

$$\textbf{Alt 1 tree biomass} = \exp^{(-1.996 + (2.32 \ln D))} \qquad (r^2 = 0.89)$$

but this equation is not to be applied to tree diameters that greatly exceed the range of the original data (40 cm). Another, more robust equation presented in recommended in FAO based upon 191 trees with diameters between 3 and 30 cm and intended for application in very dry forests <900 mm yr-1 is:

$$\textbf{Alt 2 tree biomass} = 10^{(-0.535 + \log10(BA))} \qquad (r^2 = 0.94)$$

Where BA is tree basal area = [(base diameter/2)^2 x pi], which is difficult to measure where trees are buttressed. Furthermore, this equation will have little application in *Acacia albida* parklands where all tree basal diameters greatly exceed the upper limit for which it was developed.. For the time being, it is recommended that the first of these three equations continue to be employed because it is suited to the large *A. albida* common in Bambey parklands, while the latter two equations (Alt 1 & 2) were developed from sets of smaller trees (but admittedly within a more appropriate climatic regime).

The necromass of logs may be estimated by recording the length and mid-point diameter of large logs (>10 cm) in order to calculate their mass through volume/density relationships (Woomer and Palm, 1998; Woomer, 2001). This approach appears to have little application in the Groundnut Basin, where firewood is in critically short supply, resulting in a paucity of fallen dead woody biomass, but it may have greater relevance in other areas of Senegal.

Improved tree sampling areas. Difficulties were experienced during field work in applying the major quadrat sampling area of 100 m^2 (Woomer, 2001) to the cultivated parkland because of extremely low tree densities. Out of immediate necessity, this area was increased to 200 m^2 (see Table 1), but this size of major quadrat remains inadequate as it too seldom encompasses trees and is extremely subject to bias. Two alternatives are recommended that may be applied either separately or together; **increase the major quadrat to 500 m x 5 m** (=2500 m^2 or 0.25 ha) or **sample all tree diameters within 1 ha** that is selected at random. When these two approaches are combined, an area of 100 m x 100 m (= 1 ha) is selected at random along the 500 m “transect” (Figure 11). Note that these larger sample areas must still be replicated before C stock estimates are made.

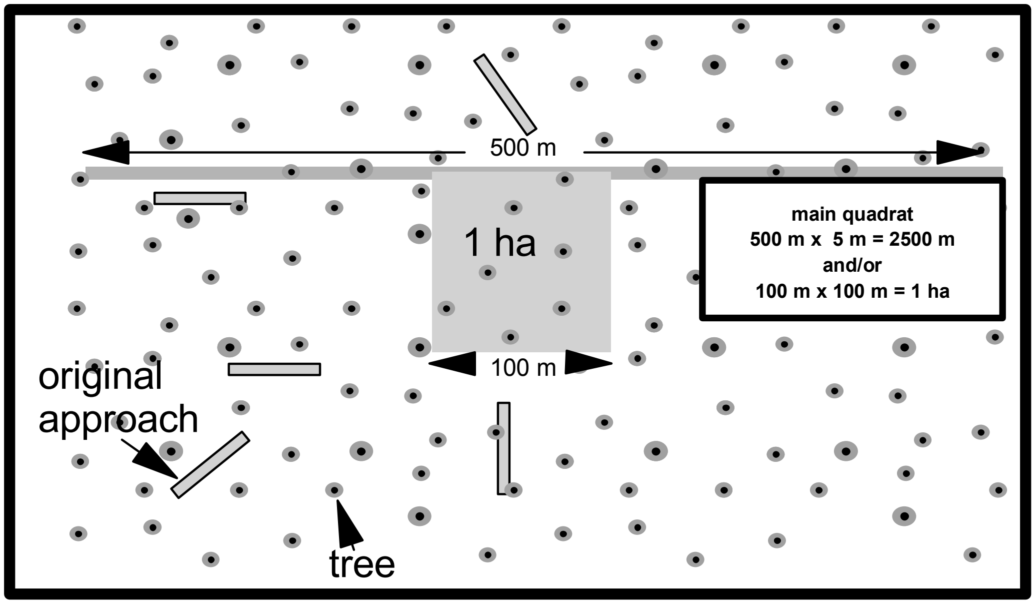


Figure 11. Suggested substitution of major quadrats for woody biomass sampling in *A. albida* cultivated parklands.

The Point-Quarter Sampling technique (Brower *et al*., 1990; Sutherland, 1996) relies on plotless sampling for tree or shrub density, biomass, or related properties and is often the method of choice when individuals are sparse and widely separated and it is too laborious to use line or belt transects. It is not the method of choice, however, when individuals are planted systematically and are uniformly spaced, as is usually the case in plantations, or when their distributions are highly aggregated. The method is explained in Figure 12.

Soil C analysis. Dr. J.K. Lekasi described methods of total soil organic carbon analysis and soil organic matter fractionation. This lecture was originally intended to be performed as a laboratory demonstration. The demonstration was not possible because a major religious holiday required last-minute changes in the workshop schedule, causing us to be at ISRA Bambey on Sunday, when the laboratory was closed. and because CSE, where the lecture was presented, does not contain a chemistry laboratory. The procedures for total soil organic carbon by wet digestion, soil microbial biomass C and physical fractionation of particulate organic matter by wet sieving are explained in step-by-step detail within the methods guidelines developed by Woomer (2001) for the workshop adopted from *Laboratory Methods of Soil and Plant Analysis: A Working Manual* by J.R. Okalebo *et al.* (1993), a reference which is widely employed in East Africa.

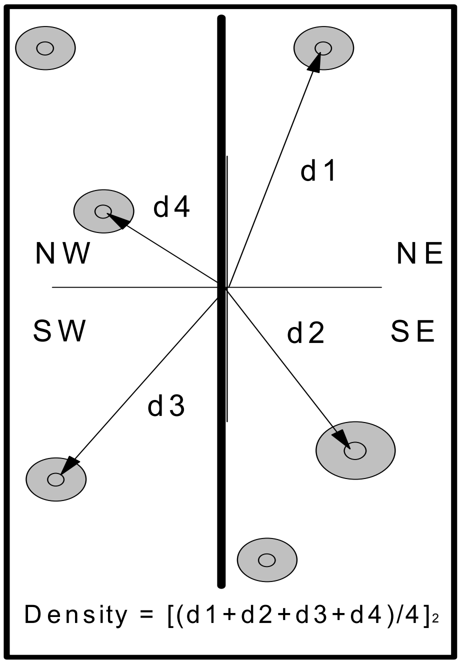


Figure 12. The Point-Quarter Sampling Technique (based upon suggestions from Larry Tieszen).

1. Select random locations along each transect to establish "points" and then identify the four "quadrants" at each point with a compass (N, S, E and W).
2. Measure the exact distance from the point to the nearest tree (middle of the tree) in each quadrant. Identify species as required in the study and take additional measurements as needed such as tree diameter, height and crown area.
3. Continue along the transect(s) to new, randomly selected, points and repeat until an adequate number of individuals has been obtained. Points must be separated by a great enough distance that a tree is NOT counted more than once.
4. Calculations (for each species as desired): a) sum all point-to-plant distances (in meters) and compute the mean value of point-to-plant; b) the mean area (meters squared) per plant is equal to the mean distance squared and c) the mean density (number per ha) per hectare is equal to 10,000/mean area.
5. Biomass, carbon, or other tree attributes can now be calculated keeping in mind that algorithms do not scale linearly, requiring individual application of the algorithm and summation.

Candidate Hypotheses for Future Research

A discussion was held on the importance of conducting research that is guided by well-worded working hypotheses. Working hypotheses were introduced as reductionist word models that are an essential component to all experimental designs and research. Science itself may be viewed as a long chain of working hypotheses that have either been accepted or rejected with either outcome contributing to the body of knowledge. Hypotheses should be stated as clearly and simply as possible but still consist of a grammatically complete statement. Properly formulated hypotheses describe relationships between phenomena and refer to the treatment contrasts and measurements necessary for their testing. Three particularly relevant hypotheses were framed based upon observations during the field practice in Bambey, two dealing with carbon balances resulting from the management of farmers' organic resources and the other relating to the special importance of *Acacia albida* as a source of organic inputs within the cultivated parklands.

Hypothesis 1. Total system C remains constant within village land use because increased soil carbon within village infields resulting from organic resource transfers compensates for reduced woody biomass C. This hypothesis assumes that organic resources from the managed outfields and periphery are effectively conserved in and around the village as soil organic matter and perennial biomass. This hypothesis may be dependant upon soil texture as sandy soil provides poor physical protection of labile soil C. It is also unlikely for more recent settlements where tree biomass is being cleared for cultivation. The importance of this hypothesis rests in its assumption that villages obtain a steady-state C level, so that managements that result in C gain are not being compromised by C decline elsewhere.

Hypothesis 2. Tree removal in cropped parklands results in reduced total soil organic carbon. This hypothesis assumes that trees provide an irreplaceable source of organic inputs to soils in the savanna ecosystem and any reduction in their biomass will also be reflected in reduced stocks of C in soils. It may be regarded as an alternative to Hypothesis 1. A corollary to this hypothesis is that C gains are most achievable through re-establishment of trees and that soil C gain is an additional benefit. This hypothesis also assumes that crop or fallow residues contribute little to soil organic C, which requires consideration in the selection of control conditions and additional treatments.

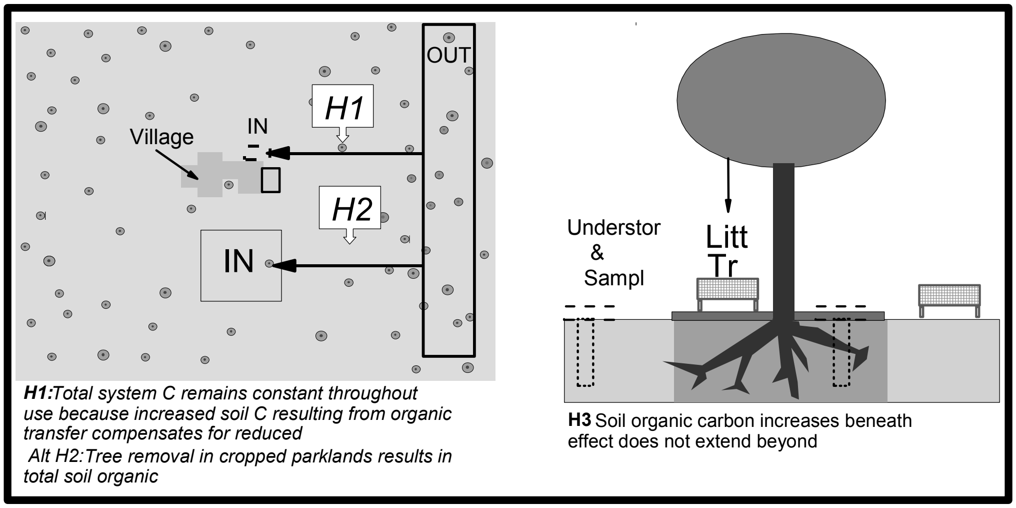


Figure 13. Three potentially useful working hypotheses addressing organic dynamics in cultivated parklands at the village and field

Hypothesis 3. Soil organic carbon is greater beneath parkland trees but that impact does not extend beyond the tree canopy. This hypothesis examines the sources of organic inputs from trees to soil, their distribution and the mechanics of soil organic matter formation. It requires that litter fall, root distribution and turn over, litter decomposition and soil organic matter fractions be measured beneath and away from parkland trees. Accepting this hypothesis partly explains the performance of crops grown under *A. albida* and suggests that tree planting and protection may be an essential component of efforts to increase soil organic C pools.

Another way to provide insight into properly conducted C dynamics research is to distribute literature of leading, peer-reviewed scientific journals. Several scientific papers on carbon estimation techniques (Woomer and Palm, 1998, Woomer *et al*., 2000) and C dynamics in small hold systems (Kapkiyai *et al*., 1999; Murage *et a*l., 2000; Woomer *et al*., 1997, 1999) were provided to participants that serve as relevant examples from Africa for further studies in Senegal. In addition, a recently published Ph.D. dissertation by Manlay (2000) based upon C dynamics in a cultivated Senegalese savanna was called to the attention of participants.

Videography and Landscape Carbon Sampling

Dana Slaymaker *from the Department of Natural Resources Conservation, University of Massachusetts, conducted this portion of the workshop and the following section is drawn from a larger, unpublished report prepared shortly after the workshop.*

The University of Massachusetts has a program seeking to develop inexpensive aerial camera/GPS systems that can attach to any local aircraft and be used by resource analysts or conservation organizations to conduct highly efficient aerial surveys with a minimum amount of training and expense. The equipment ranges from simple 35 mm camera setups that can be flown, processed and printed in one day to fairly sophisticated digital video measurement systems that can calculate the standing biomass of a forest canopy. The overall goal is to link satellite, GIS and ground data in a multi-staged interpretation of the terrain. The workshop included: field measurements of crown and breast height diameters of trees in cultivated Bambey parklands, the field videography of the same area to demonstrate counts and crown measurements of trees on a per hectare basis, and simple aerial coverage of selected villages in Bambey that are currently under study by the SOCSOM research team.

Bambey Field Practice. Information on breast height (dbh) and crown diameters was collected for 14 mature trees, mostly *Acacia albida*, in cultivated parklands near the ISRA-Bambey Station. These tree crowns were usually severely pruned for firewood (Photograph 5). Trunk diameter at breast height was measured with a dbh tape and the crown area determined by calculating the height above eye level of the crown with an inclinometer, then estimating two perpendicular radii of the crown by standing at the trunk and measuring the inclination from vertical to the edge of the crown (Figure 14 & Photograph 6). The data was tabulated in Excel, calculating estimated crown areas of each tree.

Photograph 5. Note small pile of firewood beside this tree, groomed from the crown for use by local village.

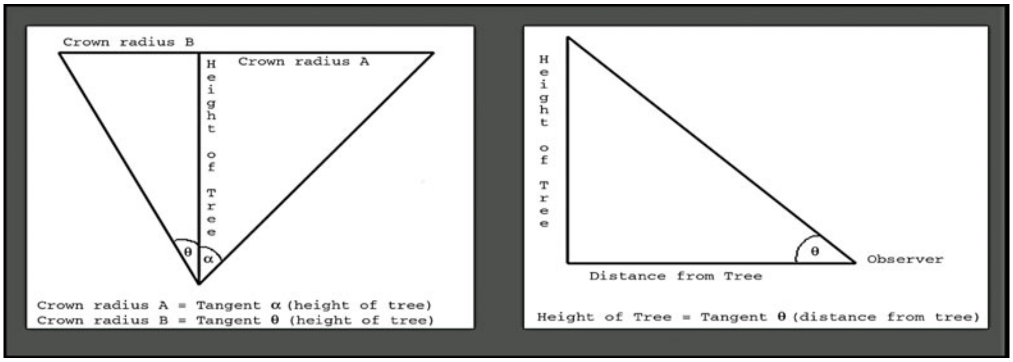
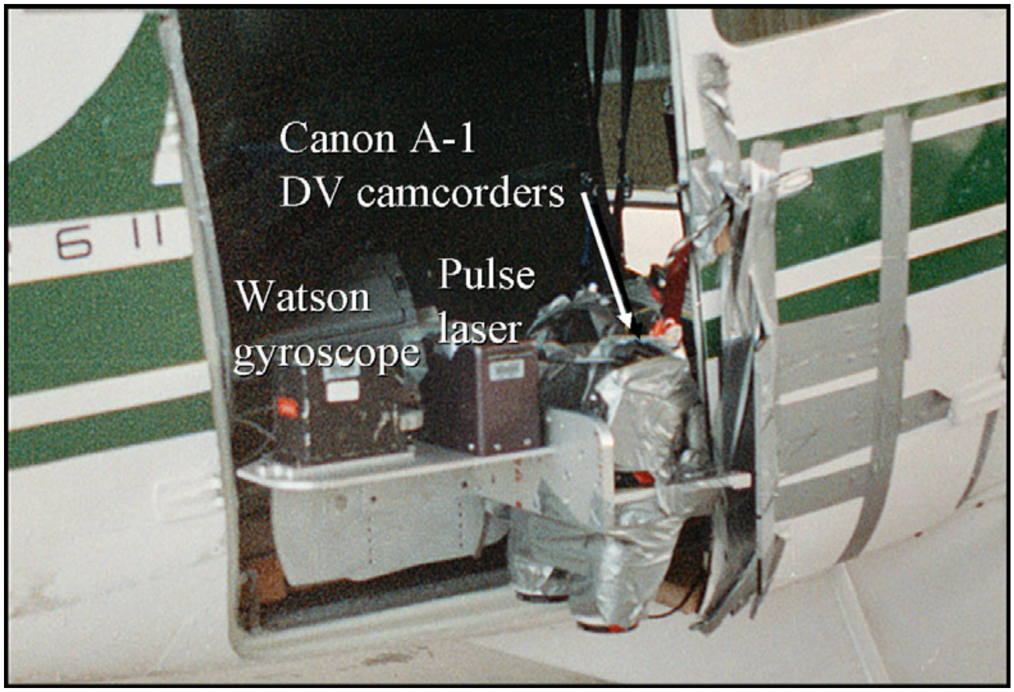


Figure 14. The crown area of each tree is estimated by calculating the height of the canopy for a known distance from the tree, then calculating two perpendicular radii of the crown from the trunk of the tree.

Photograph 6. An inclinometer measures the angle of view from either horizontal or vertical. In this case, the height of the crown above the student's eye was calculated from a distance of 50 feet from the trunk of the tree. The student then stood at the base of the tree and measured the angle out to the canopy in two directions at 90 degrees to each other.

Aerial Survey and Frame Sampling Digital Video. The purpose of the field measurements collected at the Bambey site was to develop a correlation between the dbh of the trees, which can be used to calculate their standing woody biomass using



Photograph 7. An aerial video camera mount attached to the door of a Cessna 206. A similar apparatus was employed on a Piper Saratoga airplane during the workshop in Senegal.

accepted allometric equations, and their crown areas which can be measured from the air. At this particular site, the small size of the sample and the un-natural pruning of the trees makes that correlation somewhat problematic but, in principal, the approach allows ground site measurements to be extrapolated over the landscape to more accurately reflect the actual size and distribution of trees in a geographically distributed sample. Given the sparse presence of trees in the open savanna of the Bambey region, the technique also serves a purpose in determining the actual range of tree density. The instrument package consists of a portable aerial camera mount that attaches to the door of a low-wing, single-engine Piper aircraft (Photograph 7).

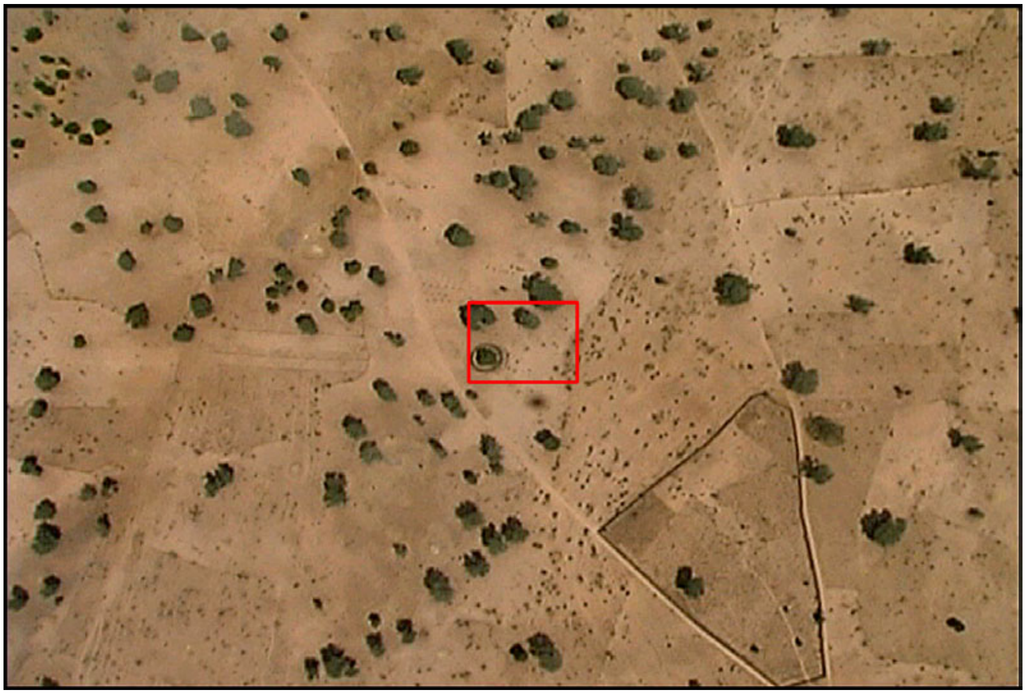
The instrument package we used consisted of two digital video cameras mounted with an attitude & heading system that gives the orientation of each exposure and a pulse laser rangefinder that measures the distance to the ground. As the video is recorded, GPS time-code is attached to each frame, allowing its precise location to be determined in post-processing.

Combined with the attitude and laser data, the data is used to generate automatically georeferenced and rectified mosaics from the video data. The two cameras are set to wide angle and telephoto settings. When flown at 1200 ft. above ground, the wide-angle image covers a swath of approximately one half a kilometer, giving an overall view of the terrain (Photograph 8). The telephoto image is set to a much narrower sub-sample of the ground down the center of the wide-angle swath (Photograph 9).

Magnification is adjusted to the size of the trees or scrubs to be measured or identified, in this case a swath approximately 50 meters wide, giving sufficient resolution to accurately measure the tree crowns. Most sampling is done on mosaics generated from the telephoto data. Several of the transects flown over the Bambey region on March 6th duplicate similar flights with Hi8 video flown by the EROS Data Center and CSE in 1994. The two sets of data could be compared as an estimate of landscape change over that period in time. These flight lines could be repeated in several more years to continue that documentation. The transects are a geographically distributed subset of the terrain that can be queried and measured over time as a statically valid sample of plant distribution and change. Large numbers of hectare plots can be established on the georeferenced mosaics, measured and re-sampled at a later date.

Aerial Survey of Selected Villages in the Groundnut Basin. Selected villages near Bambey were also photographed from a higher altitude (6,000 ft. above ground) using a 35 mm camera to demonstrate an application of small format aerial photography. The complete camera/video setup costs less than $1,500.00, forming a simple, survey

Photograph 8. A typical village and surrounding cultivated parklands in the old groundnut basin.



Photograph 9. Single video frame from the wide-angle camera, covering approximately one half a kilometer. The red outline marks the location of the corresponding zoom frame (Photograph 10).

System when combined with a GPS and a laptop containing ArcView software. Prior to the flight, the location of each target village was determined and entered into an ArcView window for on-board navigation. During post-processing, the GPS time for each target exposures could be queried from the flight data log and compared to the imprinted time of each 35 mm image to identify the correct exposures over each target. Each village was also photographed with 60% overlap for stereo viewing (not presented). Parkland land use by one of these villages is presented in Photograph 8. Woody biomass appears to be concentrated in and around this village and in the distal village outfields, an observation that was common to the other villages as well.

Opportunities for future applications. The *Centre du Suivi Ecologique* has significant computer and GIS capacity in house. They use image processing of satellite imagery, as well as existing photography, in their present operations and have access to reasonably priced planes that can be easily adapted to small format aerial camera and video use. We feel that a regular program of monitoring with a video and

Photograph 10. Matching zoom frame set with sufficient resolution to measure tree crowns. Note that the tree to the lower left appears to be protected by a "fence" of dried sticks.

35 mm (or digital) camera system would be invaluable to their efforts to document land use and the rebuilding of their carbon stocks, and we would be interested in helping them develop that capacity in further workshops and training programs.

The usefulness of our methodology for measuring above-ground woody biomass in this environment remains to be seen. The sparse number of trees per hectare (5 to 15) and the unnatural pruning of their crowns for firewood may make it difficult to establish a sufficient correlation between dbh and crown diameter to confidently estimate biomass from aerial measurements. On the other hand, the surviving trees in this area are of a few relatively consistent size classes and it may be possible to extrapolate ground data across the transects simply by counting the number of trees per hectare in each class. In any case, considerably more ground data would have to be collected before these determinations can be made. The challenge in the groundnut basin is to find mechanisms that restore land managers' organic resource capital in soils and vegetation. In the latter approach, aerial survey techniques represent an irreplaceable tool in monitoring and evaluation of parklands, natural savannas and agroforestry/tree plantations.

Group Synthesis

I. Plenary Discussion 1: Constraints and Appropriate Technologies

Following the field trip to Santhiou Lam Village in Bambey, and discussions with villagers, plenary discussion was held after returning to Dakar on farming system constraints, possible technical interventions and how these technologies relate carbon dynamics. Pressing problems expressed by Bambey farmers, with evidence for the claims in parenthesis, include:

1. **Chronic water shortage** (no dry-season cultivation, well is too slow to refill).
2. **Insufficient cash** for investment in farm inputs (unable to purchase mineral fertilizers).
3. **Inadequate weed control** including striga, indicating lack of labor during rains (Village Head reply to the question "if your visitors (us) were put to work, what would you have us do?").
4. **Declining soil fertility**, resulting in greater striga damage (no understanding of biological nitrogen fixation, visible wind erosion and prevalence of burning of surface residues prior to planting).

Technical options. A roundtable discussion was held with every participant offering at least one possible intervention. A list of 22 technical interventions or farmer actions resulted, with many of the suggestions overlapping. These options were condensed and classified as follows:

1. **Better Recycling of Organic Resources.** Promote the use of organic resources for better nutrient recycling, including reduced burning and facilitating transfer of organic material from village to outfields.
2. **Integrated Nutrient Management**. Improve availability of mineral fertilizers (through subsidy) and make their application more efficient by managing organic-inorganic interactions.
3. **Increase Biological Nitrogen Fixation.** Increase system nitrogen inputs through symbiotic N_2-fixation by intercropping millet with legumes (*V. acutifolia* Tepary bean or *V. aconitifolia* moth bean and by practicing greater frequency of legume rotation (cowpea and groundnut)
4. **Increase Woody Biomass.** Increase system woody biomass by protecting or increasing A. albida in cultivated parklands, facilitating boundary tree planting and live fences (neem, others) (possible allelopathy) (pruning to reduce competition), by marking individual land holdings with woody plants and by establishing woodlots and orchards in annual croplands.
5. **Reduce Land Use Intensity**. Reduce intensity of land use through the establishment of grazed fallows, livestock fodder banks and community-managed livestock enclosures (humans remove deadfall and green chop only).

6. **Indirect measures**. Particularly water harvesting where soil texture permits (tie ridges and micro-dams) and through striga chemical control (establish a project for one-time application of strigol).

II. Plenary Discussion 2 : Relating technical interventions to carbon offsets and moving forward:

1. **General Strategies.** Define and communicate opportunities for carbon sequestration in terms of increasing organic resource availability. Carbon sequestration is a new approach to an old problem, organic resource depletion. Assisting farmers with animal transportation facilitates organic resource use. Composting technologies are under-utilized. Proposed interventions should take into account farmers needs, abilities and interests.
2. **Identify development opportunities**. Establish demonstration trials in village areas that employ technologies that improve soil fertility, facilitate organic resource availability and increase soil organic carbon. Researchers can then measure carbon gains that result. Assist farmers to develop more systematic means of applying organic inputs to soil and to develop improved manure handling and storage techniques. Capacity building among researchers and stakeholders in the area of carbon sequestration. Determine the larger social benefits resulting from carbon sequestration projects. Inform the public about the consequences of large bush fires.
3. **Establish research priorities**. Develop technologies for re-vegetation of abandoned pit mines and predict carbon gains from the land reclamation. Similarly, documenting the carbon gains resulting from dune stabilization and desertification control projects will serve as positive examples for carbon sequestration efforts. Improve techniques of water harvesting in order to improve plant productivity (micro-dam, tie ridging). Recapture of evaporation with mulch and cover. Improve techniques of water harvesting in order to improve plant productivity (micro-dam, tie ridging). Recapture of evaporation with mulch and cover. Carbon sequestration occurs slowly in natural ecosystems, and attempts to speed up the process in managed systems remains poorly understood or may prove futile, especially soil organic C in sandy soils. Agroforestry research remains an important means to increase the woody biomass carbon stocks in degrading croplands but the selection of suitable, multi-purpose tree species are limited. Increase crop density during wetter years to achieve higher plant productivity and formation of SOM.
4. **Define "Best-bet" technologies**. Which are the different "best-bet" technologies for carbon sequestration in the different ecological zones and land uses in Senegal? Where is tree planting most important? Which soil conservation techniques are most appropriate and where? Improved soil fertility and water management in field crops will improve farmers' livelihood and increase soil organic matter, resulting in (presently unknown) carbon sequestration. Establish useful trees, especially fruit trees in the savanna,

cropped parklands and adjacent to villages. Link C sequestration studies to ongoing development projects.

5. **Understand policy dimensions.** Land tenure issues should be reconsidered in terms of their promotion of C sequestration in the mid- and longer-term (e.g. 2 year fallow limit). Conduct village meetings regarding land tenure constraints toward investment in external farm inputs. Explain policy dimensions. Intensify agricultural production as a national policy to allow for less intensive land use sequestering carbon elsewhere (fallows, land set-asides). Cost:benefit analysis of short-term investment in planned farm improvements and their effect on carbon sequestration.

III. Working Group Reports

Three Working Groups were formed on the morning of the workshop's final day after a short plenary discussion on working group topics. At first it was suggested that the participants break into three groups, one each addressing research needs in Podor, Bambey and Velingara, respectively. Given the status of carbon studies in Senegal, the research needs are fairly basic throughout the ecological zones, and this approach was waived in favor of division into three thematic groups with the following assignments:

1. **Collaboration in carbon studies and projects.** Which organizations have ongoing projects related to carbon sequestration and what are their needs? How may organizations better work together in complimentary and fuller collaborative modes?
2. **Policies affecting carbon stocks in Senegal.** What are the specific policies that impact carbon stocks in Senegal? Are these policies resulting in positive or negative impacts? How effectively are policies and regulations enforced? What are additional policy options?
3. **Prioritizing "Best-Bet" technical options.** What are the most promising technical innovations and future actions and where in Senegal are they most appropriate? Which options are most complimentary?

Working Group I: Policy issues affecting carbon sequestration and organic resource management.

Land tenure issues and customary laws. A paucity of fallow and pastureland in areas with large demographic pressure may be attributed to regulations that land not be withdrawn from cultivation for more than two years. Similarly, land may not be rented to others for periods of more than two years, reducing incentive to those better able to invest in land improvement. Severe market constraints for investing in soil fertility management exist following removal of fertilizer subsidies. Large areas of non-cultivated savanna and grazed fallow occur in southern Senegal but current migration trends are rapidly reducing their extent. Insecure and inexact land tenure (no title deeds) reduces the willingness of land managers to invest in land improvement, including soil fertility inputs and tree planting.

Possible actions include improved longer-term access to land at different levels: from long-term rents and fallow/pasture (ex 10-100 years) to granting title deeds to traditionally held land. Providing greater flexibility to local decision-makers and at the smallest administrative unit (communauté rurale) that allows land managers incentive to invest in tree planting and land improvement.

Land use systems and supportive policies. River valleys throughout Senegal provide opportunities for intensive agriculture through policy support for irrigation projects. Irrigated lands will provide opportunities for C sequestration when planted with tree crops, including boundary tree plantings. Similarly, the establishment of tree crops or pasture on "dieri" lands will provide opportunities for C sequestration without taking these higher potential lands out of production.

Central Senegal suffers from severely degraded resources that have greatly reduced the total carbon stocks in this densely populated, continuously cultivated area of the country. This is the area that serves as the source of out-migrants and their negative impacts on C sequestration to the south. Policies are required that promote intensification and diversification of (year-round) market agriculture that combines annual and perennial crops. Intensified market agriculture will result in employment and less out-migration as well as providing opportunity to restore the most degraded lands through mid-term fallow and grazing.

Policy options available to improve the livelihood of farmers in central Senegal and lead to likely improvement of carbon stocks include:

1. Facilitate access to credits for improved, diverse crop seeds and tree seedlings, fertilizer and means of transportation.
2. Promote increased knowledge related to rural capacity building including water harvesting, agroforestry, organic resource processing production (compost, high-nutrient manure).
3. Improve and promote value-added processing and marketing of agricultural products through the reduction of import and taxes on equipment such as solar dryers and reduced export taxes of finished products. Processing neem into export products may pose a special opportunity, as the neem tree is well suited to the area's growing conditions.
4. Assist in obtaining financial assistance for research and development projects targeting increased availability of farmers' organic resources from donors and development partners, including potential purchasers of accrued carbon.

Land managers in southern Senegal have yet to deplete their system C stocks but the steady influx of migrants from the central Senegal will steadily result in carbon loss as dry woodlands and savanna fallows are brought into continuous cultivation. Regulations may be made that require a minimum number of trees to remain within lands brought under cultivation, for example 15 mature trees per ha and when this minimum is not met land managers may be required to replant trees. Strong evidence exists that isolated trees in cultivated parklands increase, rather than reduce, crop yields.

Policy options available to improve the livelihood of farmers in southern Senegal include many of those covered above for central Senegal and also include:

1. Intensification and diversification of agriculture combined with rigorous control of protected areas.
2. Support is needed for subsidies of butane gas and availability of improved stoves ("ban ak suuf") to reduce dependence on charcoal
3. Need exists to calculate appropriate quota for charcoal and fire wood, to delineate corresponding surfaces, impose more rigid restrictions and controls on wood gathering and to enforce regulations requiring reforestation.

Working Group II. Collaboration and teamwork in carbon sequestration efforts in Senegal

The working group session opened with a reminder that too little successful inter-organizational collaboration has occurred in the past despite past workshops that have included similar "collaboration working groups". Members agreed that many project activities are viewed from an institutional context with collaboration between organizations either discouraged or their potential benefits not well understood. Better teamwork is required that combines expertise in chemical analyses, resource mapping, agro-ecology, forestry and agroforestry, socio-economics and remote sensing. Members of the collaboration working group were asked to describe their organization's activities and needs through collaboration.

Leadership in Natural Resource Mapping. CSE has expertise in mapping of biomass, land use changes, vegetation and poverty. It works in the areas of GIS, remote sensing and aerial image interpretation. It has an ongoing partnership with USGS/EROS Data Center and has organized symposia and training workshops, including this one.

Leadership in carbon analysis. ISRA has soils laboratories in Bambey and St. Louis and is able to analyze samples for C and nutrients. It also has strong capacities in socio-economics. ISRA will collaborate with KARI (Kenya) to develop a reference sampling project to address the quality of analytical results. ISRA charges CFA 3000 per C analysis (conducted in duplicate) and performs many other analyses (including texture). A price list for analyses by ISRA is available, but poorly distributed (e.g. was not brought to this meeting). Discounts are extended to research collaborators and for large numbers of samples.

Leadership in soil mapping. Soils Bureau prepared 1:50,000 soils maps for 350,000 ha in the Kaffrine pilot area. It is working with CSE in translating this information into a GIS. Also maps are available for the suitability of the major field crops. It is willing to include C sequestration in its activities. It is working on wind erosion in northern Senegal. SB works with farmers' associations and NGOs in composting, and use of rock P near Kaffrine. The participant from SB lacks convenient access to a computer and will be unable to continue with CENTURY. *Institut de Recherche pour le Développement* (IRD, formerly ORSTOM) also has expertise in soil organic matter management.

Leadership in tree germplasm and biodiversity. The ISRA, Forestry Department, has projects in tree domestication. It focuses upon fruit-bearing indigenous species. Need to assess the carbon sequestration from tree planting. Another project examines seeds of forest trees because current germination is very low. Presently examining 100 provenances, mostly indigenous species that serve to protect tree biodiversity. Plan to establish 5 ha for each of 10 fruit and wood species. Agroforestry is also included within this Department. The Department works with the Ministry of Environment on dune stabilization with *Casuarina*. Concern was expressed that existing regulations requiring tree replanting following harvest for charcoal are not presently enforced.

University role in training and manpower. University of Dakar has expertise in graduate-level training. Ongoing project activities include lowland watershed management and in land reclamation.

Need for land reclamation. Ministry of Industry and Mining has identified abandoned mine pits that are prime candidates for land reclamation and invites others to assist in the design of projects intended to re-vegetate these areas. Regulations on land reclamation of abandoned mines are not being enforced. Fuller description of these degraded areas is required. The participant from SB lacks convenient access to a computer and will be unable to continue with CENTURY.

Opportunities for future collaboration. Provide the National Committee on Climate Change the outputs of this workshop and then continue to offer scientific and technical advise on carbon stocks, dynamics and modeling. The Committee is led by Col. Mbarek Diop and its members include Assize Toure (CSE), Madeleine Diouf (Ministry of Environment) and 28 additional members.

The best way forward is to design a series of projects that involve several organizations within Senegal and elsewhere. Possible donors for these projects include GEF (through UNDP) and IDRC (Canada with offices in Dakar) and USAID. Possible topics for these collaborative proposals include:

- Carbon stocks, dynamics and modeling in densely cultivated lands in Senegal's Groundnut Basin: Can carbon offsets be realized? (USAID)

- Carbon sequestration and biodiversity in restored lands of Senegal, including coastal dune stabilization, exhausted pit mines and desertification control efforts. (GEF)

- Rehabilitation of degraded mangrove wetlands resulting from seawater influx.

- Biodiversity inventory and conservation of endangered tree species in southeast Senegal.

- Other research topics suggested by additional Working Groups.

Working Group III: "Best-bet" technologies for organic resource restoration and carbon sequestration in different zones of Senegal.

The working group presented several "best-bet" technologies designed to meet specific constraints residing in different locations of Senegal (Table 2). It may be argued that this working group was imprecise in addressing their assigned topic, failing to prioritize and eliminate some of the many technical interventions raised within the earlier plenary session. However, a matrix was developed that identified promising technologies to the different agroecological zones in Senegal, although the connection of some of these technical options to C sequestration is unclear. Nonetheless, it is advisable that the "wish list" of "best-bets" presented in Table 2 be further narrowed and prioritized as many of them have only peripheral or indirect relationship to carbon sequestration.

In addition to best-bet technologies, Working Group III presented a list of several tree species recommended for different agroecological zones of Senegal. This list resulted from efforts during a recent CSE workshop on desertification control and reforestation (Table 3).

Table 2. "Best-bet" technologies for carbon sequestration in Senegal.

Zone	Constraints	Best-bet technologies
Podor Arid Zone (200mm)	• Water shortage • Salinity • Low soil fertility • Wind erosion • Lack of appropriate tree varieties • Lack of fodder • Bush fire	• Breed and plant adapted trees - Boundary planting on irrigated land - Use of halophytic tree species • Intercropping salt tolerant crop variety and Sesbania rostrata (i.e. rice) • Restauration of parkland (Arabic gum, and fodder tree) • Manure application • Bush fire control
Bambey & Kaffrine Semi-arid zone (450mm/ 700mm)	• Declining soil fertility • Low soil moisture • Shortage of water for rising tree seedlings • High human and livestock population pressure leading to land degradation • Water erosion • Bush fire	• Intensify-diversify agriculture • Alternative source of energy • Increasing Acacia albida, fruit and multipurpose trees in parkland, boundary trees and shrub planting, • Livestock fodder banks and community-managed livestock enclosure • Assisted tree regeneration • Bush fire control • Micro dams
Velingara Sub-humid zone (1100mm)	• Bush fire • Water erosion • Deforestation (charcoal, farming)	• Alternative source of energy • Bush fire control • Participatory Forest management • Micro dams • Appropriate soil conservation measures

Table 3. Tree species useful in Senegal for carbon sequestration

Niayes: *Casuarina equisetifolia, Faidherbia albida, Cocos nucifera, Prosopis africana, Parinari macrophylla, Adansonia digitata*

Vallee et delta du fleuve Senegal: *Acacia nilotica, Acacia tortilis, Zizyphus mauritiana, Acacia senegal, Balanites aegyptiaca, Faidherbia albida, Eucalyptus sp., Prosopis juliflora, Khaya senegalensis, Casuarina equisetifolia, Parkinsonia aculeata, Acacia mellifera, Acacia mangium, Acacia auriculiformis, Leucaena leucocephala, Dalbergia melanoxylon*

Zone agro-sylvo-pastorale centre et Sud-est: *Acacia senegal, Afzelia africana, Vitellaria paradoxa, Cordyla pinnata, Daniellia oliveri, Faidherbia albida, Khaya senegalensis, Parkia biglobosa, Pterocarpus erinaceus, Prosopis africana, Sterculia setigera, Tamarindus indica, Zizyphus mauritiana, Combretum spp., Bombax costatum, Oxytenanthera abyssinica, Borassus aethiopium, Adansonia digitata*

Zone sylvo-pastorale: *Acacia senegal, Acacia nilotica, Acacia tortilis raddiana, Acacia laeta, Balanites aegyptiaca, Dalbergia melanoxylon, Faidherbia albida, Pterocarpus lucens, Zizyphus mauritiana, Boscia senegalensis, Acacia seyal, Combretum glutinosum, Commiphora africana, Salvadora persica, Bauhinia rufescens, Sclerocarya birrea, Cadaba farinosa*

Bassin arachidier: *Anacardium occidentale, Balanites aegyptiaca, Detarium senegalense, Faidherbia albida, Khaya senegalensis, Parkia biglobosa, Prosopis juliflora, Tamarindus indica, Zizyphus mauritiana, Cordyla pinnata, Pterocarpus erinaceus, Bombax costatum, Eucalyptus spp., Melaleuca leucocephala, Acacia seyal, Tamarix afila, Tamarix senegalensis, Acacia holosericea, Phoenix dactylifera, Azadirachta indica, Daniellia oliveri, Ceiba pentandra, Sterculia setigera, Parinari macrophylla, Cassia sieberiana, Bauhinia rufescens, Acacia mellifera, Leucaena leucocephala, Avicennia sp., Rhizophora sp., Adansonia digitata, Gliricidia sepium, Acacia mangium*

Zone Forestière Sud*: Afzelia africana, Cordyla pinnata, Daniellia oliveri, Elaeis guineensis, Faidherbia albida, Khaya senegalensis, Parkia biglobosa, Prosopis africana, Pterocarpus erinaceus, Tamarindus indica, Zizyphus mauritiana, Saba senegalensis, Eucalyptus sp., Carapa procera, Tectona grandis, Anacardium occidentale, Acacia mangium, Diospyros mespiliformis, Erythrophleum guineense, Avicennia sp., Rhizophora sp., Gmelina arborea, Detarium senegalense, Adansonia digitata, Gliricidia sp.*

Workshop Evaluation

Participants' impressions of the workshop were evaluated through a short, formal survey consisting of 16 multiple choice and 8 open-ended questions. The survey was separated into three sections addressing 1) instruction in use of the CENTURY Model (12 questions), 2) estimation of C stocks (9 questions) and 3) suggestions for improving future workshops (3 questions). The survey was available in both French and English language versions with participants responding in their language of choice. The survey was delivered to participants during the final morning of the workshop and returned that same afternoon. Between 12 and 15 responses were obtained for each survey query. Multiple-choice responses were compiled and expressed on a percentage basis to normalize the differences in the number of replies. Participants' agreement with various statements concerning the workshop and instructors' effectiveness appear in Appendix 4.

The replies concerning workshop objectives were largely favorable with 54% and 26% of the respondents either supportive or strongly supportive of the workshop components, respectively (Table 4, calculated from Appendix 1). Participants tended to be more supportive of the CENTURY modeling sessions (90% support) than the C measurement field work (66% support). Participants were strongly supportive of the documentation accompanying the CENTURY Model (53%), the effectiveness of CENTURY Model demonstrations (46%) and in instruction on the operation of field tools (38%).

Table 4. Summary of participants' impressions of the overall workshop and its two major components, CENTURY modeling and field estimation of C (calculated from Appendix 4).

Component	Participants Impressions			
	Very satisfied	Satisfied	Ambivalent	Dissatisfied
Overall workshop impressions	26%	54%	13%	7%
CENTURY modeling sessions	32%	58%	7%	3%
Field estimation of carbon18%	18%	48%	22%	11%

Overall, the frequency of neutral (or uncertain) replies was 13%, suggesting very little apathy toward the workshop as a whole. Participants disagreed with only 7% of the survey's statements concerning accomplishment of workshop objectives, again suggesting overall success of the workshop as a whole. While participants voiced support for the mechanics of CENTURY Model instruction (100%), they were less supportive with the use of specific examples and the explanation of interpreting model outputs (27% neutral or dissatisfied). Participants were less satisfied with the field-based portions of the workshop. While 92% agreed that the techniques for field estimation were adequately explained, only 51% felt they were provided sufficient opportunity to obtain practice with those techniques. Participants were least supportive of the visit to Santhiou Lam Village, with 42% expressing ambivalence or dissatisfaction with the description of historical and current land uses, and 72% believing that insufficient effort was made to address farmers' perceptions and concerns over soil management.

Much of participant satisfaction with the course may be explained by the design and scheduling of the workshop itself, and compliance with that schedule. The portions of the course devoted to the CENTURY Model were well supported by four Resource Persons and an adequate computer laboratory. The time originally scheduled toward mastery of the CENTURY Model (4.5 days) remained unchanged despite a last minute shortening of the workshop by 1.5 days. In summary, the resource persons supporting the use of the CENTURY Model were experienced in that area and provided ample time and facilities by the local organizers to undertake their task.

The duration of the workshop was reduced by 1.5 day, with this time subtracted entirely from field-based practice. Participants were sensitive to this shortcoming as 21% indicated that too little time was allocated to performing field work while 20% responded that too much was expected (Appendix 4C). Some resource persons who were critical to the CENTURY Modeling instruction could not accompany the participants into the field, which disappointed some of the participants. Time spent in the village was clearly insufficient for genuine dialogue to be established between stakeholders and workshop participants. Finally, some Senegalese participants had greater expertise in the land use systems selected for C measurement than did the resource persons introducing them to those measurements and this expertise was not readily incorporated into field-based instruction.

CENTURY Participants when queried concerning the improvement of future workshops raised many useful suggestions. While these comments arose from open-ended query, they may be summarized as follows:

1. Prepare more of the crucial instructional materials in French for use by colleagues and workers with lower abilities in English (e.g. field and laboratory technicians).
2. Place greater emphasis on specific land management options and their potential to sequester carbon in degraded lands that are most appropriate to different agroecological zones of Senegal. Land management options should be more specific in terms of plant species and land rehabilitation procedures.
3. Field methods should be tested in advance for their appropriateness to diverse Senegalese conditions, and should be better backstopped by laboratory methods.
4. Provide clearer opportunities for follow up C studies including means for collaboration and information sharing.

Some comment on these recommendations is warranted. Translating workshop materials is a desirable goal, but given the poor French language abilities of most English-speaking resource persons, one that would best be undertaken by bilingual local organizers. Being more specific concerning the selection of land management options would again require greater involvement of local expertise in advance of the workshop and is likely better considered as a goal for subsequent projects. The short length of the training workshop required that training priorities be established, and unfortunately, laboratory techniques for C determination were relegated to lecture setting rather than providing hands-on training. Clearly, C studies require accurate C measurement and this is an issue that must be addressed in future project design. In defense of the organizers decision, C analysis is usually performed by a different group of research supervisors than those responsible for the design, implementation and interpretation of field C studies, and this workshop was intended for the latter group. Finally, short-term visits by expatriates may facilitate new understandings in C dynamics and management, but formalizing these within national programs is largely the responsibility of the participants themselves. New research activities that emerge from later activities of the current project should encourage multiple participation within Senegal with cooperators making greatest use of their particular strengths, whether it be in remote sensing, field experimentation or chemical analyses.

Conclusions and Recommendations

This workshop was intended to provide the training and establish the framework for subsequent, collaborative research activities in carbon studies for national research programs in Senegal. It was designed to provide a broad background in understanding carbon dynamics at several scales that included on-site measurement of total system C, rapid aerial estimation of woody biomass C, interpreting land use changes over time using maps, photographs and satellite images, understanding stakeholders' perceptions of organic resource management, the biogeochemical modeling of C dynamics for important land use systems and to establish priorities for subsequent research. These were ambitious goals for a two-week training workshop that was largely met by involving a series of highly experienced and specialized "external" resource persons.

These resource persons not only presented materials falling within their areas of specialization in a competent manner, but also provided participants with a wide range of literature, computer software and field tools necessary for future undertakings by Senegalese researchers. It was the assumption of the international organizers that the sum of the individual expert instructors' messages would prepare the Senegalese scientists for the C studies and understanding necessary for participation in sequestration and trading mechanisms. Local organizers "bought" into this assumption but must now become more active and directly involved participants in further research, training, and natural resource management interventions. Although the participant's evaluations were largely very favorable, the real success will be shown by their subsequent involvement in carbon and management issues.

Contribution to capacity building in natural and agricultural resource management by a Senegalese institution was the overall, but perhaps understated, objective of the workshop and should be the ultimate goal of future projects. The design of an innovative research strategy toward carbon management that benefits impoverished land managers is an important, but not exclusive, mechanism toward that end. The largely unsuccessful period of post-colonial scientific relations between African "national" and western "international" scientists is coming to a well-deserved close.

Efforts now need to be directed toward genuinely collaborative scientific problem solving and capacity building. The following comments are intended in this constructive manner:

1. **Consolidate gains and maintain momentum.** Much was accomplished during the training workshop. For the first time, scientists now have the ability to collect and compile information on ecosystem C dynamics in a standardized, credible manner. Many participants have sufficient understanding of the CENTURY Model to develop and interpret simulations of land use changes at additional sites. National organizations recognize their

comparative, complementary strengths and have agreed to work together toward a common goal and to draw upon the assistance of international partners while doing so. The confluence of interest between land managers who must reacquire and better manage organic resources and the needs of global society to mitigate atmospheric change through carbon offsets in biomass and soils is better recognized by Senegalese scientists (and a few from the US as well). ***The gains from this workshop must be formalized through the development and equitable award of a collaborative research project designed to better understand the carbon offsets achievable through improved management of Senegal's natural and agricultural resources.***

2. **Stimulate full collaboration**. It is important that future activities be developed in a fully collaborative and transparent manner. This refers to relations between the recently trained scientists belonging to different national organizations and between national hosts and international partners. National scientists remarked that collaboration usually ends as soon as another "collaborating" organization receives the funds. Local participants should collaborate with international colleagues as they approach international donors. Funds are necessary for further research in C sequestration but money is not necessarily the only ingredient to foster success, and collaborators should reach this realization. ***Individual scientists must be active proponents of their specialty areas and should be expected to draft those portions of proposals in which they will later be involved. Collaborative proposals should be developed during 2001 for future funding or momentum gained from the workshop will be placed at risk.*** The joint cooperation in the proposal to the McKnight Foundation is a good start in truly collaborative work in this area.

3. **Remember tools for the future.** Some resource persons provided training with equipment that could not be left with national scientists, but rather introduced equipment to them, which then needed to be returned to their home countries. The values of the analytical approaches, however, were clearly demonstrated, and plans are being formulated to secure the necessary instrumentation. Although CSE invested in computers and a new training laboratory, other participants do not have the access to computers needed to continue the work initiated during the workshop. Donors, international cooperators, and national agencies need to understand the value of modern technology and the contributions that can be made to international science and local development. ***Whenever possible, research equipment used in training should remain in the host country for further use by national scientists, or, when deemed valuable, plans to secure necessary equipment should be made.***

4. **Better empower local cooperators.** Local organizers may have required additional funding to become fully involved within the workshop. Local organizers were provided repeated opportunity to contribute to the design and activities of this workshop but chose a relatively passive role, focusing upon logistics, an important role and one that was well performed. Some tensions were raised concerning proprietary research and the sharing of data between collaborators were identified and discussed. ***Senegalese scientists, international organizers and resident expatriates should formalize understandings concerning research goals, authority over study areas, data sharing and financial responsibilities.***

5. **Involve the brokers.** Documenting C gains and selling that C to a buyer responsible for CO2 emissions are two related but non-identical issues. The workshop did not include components dealing with creditation, verification, monitoring and sales of C offsets. The importance of this for Senegal was recognized, and a stronger involvement of the National Carbon Team, formulated at the earlier SOCSOM conference, was encouraged. ***A mechanism must be found to incorporate expertise in formal C offset projects as required in the future when researchers are confident that realistic C offset targets are identified and if Senegalese policy makers decide that such projects are in their country's best interest.***

6. **Comments on videography.** An elegant but technically-demanding method of employing aerial video photography to calculate woody biomass based on canopy cover as a proxy for tree diameter at breast height was presented by Dr. Dana Slaymaker. This technique requires that a video camera be linked to a GPS through a common flight clock and that altitude be measured by laser emitter that is corrected for aerial tilt. Dr. Slaymaker and two fellow resource persons conducted aerial measurements of the Bambey study area two days previously. A multimedia presentation was then made by Dr. Slaymaker that included identification of the technical array of equipment, sample past aerial reconnaissance and their applications, instructions on data processing procedures and the presentation of results from Bambey. If the procedures can be calibrated and validated to Senegal's parklands and savannas, it will provide an extremely time-effective survey tool. Canopies in cultivated parklands are carefully managed by farmers, and certain assumptions concerning the relationship between canopy cover and tree diameter developed for natural ecosystems may be non-applicable. Special efforts must be made to transfer videographic techniques and capacity to Senegalese research organizations in a cost effective and sustainable manner. **Canopy management by farmers in the cultivated parklands of the Groundnut Basin, and its influence on tree diameter and biomass is a worthy research topic. More effort must be made to identify Senegalese counterparts and they should be invited to participate on aerial missions and to be involved in step-by-step processing of data.**

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Appendix 1. Resource persons and participants at the Landscape Carbon Sampling and Biogeochemical Modeling Workshop

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Appendix 2. Venue, program and presenters at the workshop.

Landscape Carbon Sampling and Biogeochemical Modeling Workshop

Venue:	25 February to 10 March 2001, Centre de Suivi Ecologique, Dakar, Senegal,
Resource Persons:	L. Tieszen, D. Ojima, W.J. Parton, S. del Grosso, G. Tappan, A. Toure, P. Tschakert, P.L. Woomer, J.K. Lekasi and D. Slaymaker
Overall Objective:	To develop capacity for the measurement and modeling of carbon dynamics in major land uses of Senegal

Approach: A two-week training workshop is held with the first week spent in training participants in the use of the CENTURY Model, and the second week devoted to field and laboratory measurement of carbon. The CENTURY Modeling sessions are computer-based, with participants working in teams of two, leading to the interpretive simulation of three contrasting ecosystems in Senegal. The field training is conducted at Bambey with participants working in teams of eight, leading to competence in estimating total system carbon based upon measurements of trees, herbaceous biomass, litter, roots and soil. The laboratory component is designed to assure quality control in the analytical determination of carbon in soil and litter samples. The workshop concludes with sessions on compiling, analyzing and interpreting the carbon dynamics within land use systems and is designed to provide preliminary recommendations to the Senegalese Clean Development Mechanism negotiators. Note that some deviation from the planned schedule occurred as noted in the main report.

Programme:

Week 1, Biogeochemical Modeling with CENTURY, CSE, Dakar

Monday, 26 February 2001, CSE, Dakar

0830-0900	Welcome to participants, round table introductions and goals of the workshop (A. Toure)
0900-0930	Introduction: the importance of measuring and modeling carbon dynamics in ecosystems (P.L. Woomer)
0930-1030	Introduction to CENTURY Model environment (W. J. Parton)
1030-1100	Morning Tea Break
1100-1115	Assignment of modeling teams and computer workstations (A. Toure)
1115-1300	Introduction to the Event.100 land management schedule (D. Ojima and W.J. Parton)
1300-1400	Lunch
1400-1500	Constructing Site and Weather files (W.J. Parton and D. Ojima)
1500-1600	Running the CENTURY Model

Tuesday, 27 February 2001, CSE, Dakar

0830-0930	Descriptions and data of the Bambey, Velingara and Podor Sites (P. Tschakert and G. Tappan)
0930-1030	Constructing realistic Crop, Organic Matter Addition, Cultivation, Irrigation and Harvest files (P.L. Woomer and D. Ojima)
1030-1100	Morning Tea Break

Tuesday, 27 February 2001 (continued)

1100-1200	Constructing Grazing, Erosion, Fire, Tree and Tree Removal files (D. Ojima)
1200-1300	Running the CENTURY Model and understanding its outputs (W.J. Parton)
1300-1400	Lunch
1400-1600	CENTURY model practice (W.J. Parton , D. Ojima and P.L. Woomer)

Wednesday, 28 February 2001, CSE, Dakar

0830-0930	Land use and carbon sequestration potential in Bambey, Velingara and Podor (G. Tappan and P. Tschakert)
0930-1000	New team assignments, six terms, two for each site (P.L. Woomer)
1000-1030	Developing site and climate files for each location (Resource Team)
1030-1100	Morning Tea Break
1100-1300	Developing Event.100 schedule files for C sequestration (Resource Team)
1300-1400	Lunch
1400-1500	Group discussion on approaches to carbon sequestration
1500-1600	CENTURY model practice

Thursday, 1 March 2001, CSE, Dakar

0830-0930	Team presentations on proposed CENTURY model C sequestration approaches,
0930-1030	Developing Event.100 files to support the proposed scenarios (Resource Team)
1030-1100	Morning Tea Break
1100-1230	Developing Event.100 files to support the proposed scenarios (Resource Team)
1230-1300	Review of CENTURY output options (W.J. Parton and S. del Grosso)
1300-1400	Lunch
1400-1600	Teams develop full Event.100 schedules and run C sequestration simulations

Friday, 2 March 2001, CSE, Dakar

0830-0900	Interpreting CENTURY outputs for land use improvement (W.J. Parton and D. Ojima)
0900-1030	Teams refine simulations and outputs
1030-1100	Morning Tea Break
1100-1300	Team meetings to discuss simulations and prepare presentations
1300-1400	Lunch
1400-1600	Working group presentations
1600	Depart for ISRA Bambey

Week 2. Methods of Carbon Measurement

Saturday, 3 March 2001, Bambey field site, CSE, Dakar

0800-0900	Introduction to tools at ISRA Bambey Guesthouse (P.L. Woomer)
0900-1300	Field practical, carbon estimation in a cultivated parkland (Resource Team)
1300-1400	Lunch
1400-1530	Field practical, carbon estimation in a grazed savanna (Resource Team)
1530-1700	Field practical, carbon measurement in tree plantations and field boundaries (Resource Team)

Sunday 4 March 2001, Bambey field site, CSE, Dakar

0830-0930	Introduction to maps, aerial photographs and satellite images (G. Tappan)
0930-1000	Travel to Santhiou Lam Village
1000-1200	Discussion with villagers and village resource tour (P. Tschakert)
1200-1300	Point distance method and tree height, canopy measurements (L. Tieszen and D. Slaymaker)
1300-1400	Lunch at ISRA-Bambey
1400	Return to Dakar

Monday, 5 March 2001, Workshop closed for religious celebration
Tuesday, 6 March 2001, Workshop closed for religious celebration

Wednesday, 7 March 2001, Bambey field site

1500-1630	Field data compilation, analysis and interpretation (P.L. Woomer)
1630-1800	CENTURY Model practice (S. del Grosso)

Thursday, 8 March 2001, CSE, Dakar

0830-1030	Root washing, sample preparation and soil carbon fractionation and analysis (J.K. Lekasi)
1030-1100	Morning Tea Break
1100-1300	Calculating woody biomass C through remote sensing (D. Slaymaker)
1300-1400	Lunch
1400-1600	Plenary Discussion 1: Constraints and Appropriate Technologies

Friday, 9 March 2001, CSE, Dakar

0830-0930	Validation of CENTURY outputs using field data (S. del Grosso)
930-1030	Plenary Discussion 2 : Relating technical interventions to carbon offsets and moving forward
1030-1100	Morning Tea Break
1100-1300	Working group discussion on prioritizing options for carbon sequestration
1300-1400	Lunch
1400-1430	Senegal's involvement in CDM negotiations (Madeleine Diouf)
1430-1500	Working Group presentations on strategies for carbon sequestration
1500-1600	Final Plenary Discussion, recommendations and closing

Appendix 3. Important field tools and their uses in a field campaign to measure total system carbon in small hold farming systems[1].

tool	application
geographic positioning system[2]	identify geographic coordinates of site and land use
local or aerial map	assist in site location, establish rapport with farmers
random number table	assist in randomization decisions
compass	assist in mapping and randomization direction
data sheets and clip board	enter DBH and labelling codes with sketch maps on reverse side
range finder[2]	measure farm and field dimensions
metric tape measure	establish 25 m central linear axis of major quadrat. measure field dimensions
diameter tape	measure tree diameter
fluorescent tape	mark approximate location of major quadrats
dial calliper[3]	measure DBH of smaller trees
1 m x 1 m wooden quadrat[4]	establish boundaries for understorey recovery
0.5 m x 0.5 m wooden quadrat	establish boundaries for surface litter recovery
hand shears	recover understorey vegetation
small hand rake	recover surface litter
hand saw	recover small trees, woody litter and larger roots
flat-bladed shovel	excavate soil and roots
bulk density cylinders[5]	recover soil bulk density samples for each land use
wooden mallet	drive bulk density cylinders into soil
flat-bladed knife	trim soil cylinders and others
plastic tarp	establish sample processing area

[1]Two sets of field tools were provided to Senegalese scientists, one each to CSE and ISRA-Bambey. Most materials were purchased in Nairobi, others (florescent surveyor's tape, plastic tarps) in the US. [2]Requests that these tools be purchased in the US were declined, but ISRA-Bambey lacks a GPS, CSE has no range finder. [3]Difficulty was experienced in obtaining metric dial callipers, requiring that ones calibrated in the English system be substituted. [4]A sample quadrat was made in Nairobi, taken to Senegal and others fabricated by CSE during the workshop. [5]Bulk density cylinders were provided by, and are presently only available to ISRA-Bambey.

Appendix 4. Participant responses to a short, formal survey of course contents and its ability to meet their expectations (survey designed and compiled by S. del Grosso).

Part 1: Survey responses addressing the portion of the workshop covering biogeochemical modeling with CENTURY.

QUESTION	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The basic assumptions of the CENTURY model were clearly described.	20%	73%	7%	0	0
The documentation provided helped you understand the CENTURY model.	53%	47%	0	0	0
The instructors presented examples to show how CENTURY has been used.	27%	67%	0	7%	0
The instructors effectively demonstrated how to run the CENTURY model.	46%	47%	0	7%	0
The computer lab demonstrations and exercises were adequate for you to learn how to modify files yourself.	26%	67%	7%	0	0
The instructors explained how to interpret CENTURY model results.	20%	53%	20%	7%	0
CENTURY is a useful tool to improve your research.	36%	50%	14%	0	0

Part 2. Survey responses addressing the portion of the workshop covering methods of carbon measurement.

QUESTION	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The instructors adequately demonstrated how to operate the instruments used to estimate C levels.	38%	62%	0	0	0
Methods used to estimate biomass C, litter C, and soil C were clearly explained.	21%	71%	7%	0	0
The participants had sufficient opportunities to practice using the different measuring instruments.	14%	37%	21%	21%	7%
The historical and current land uses of the field sites selected for measurements were effectively described by the instructors.	8%	50%	34%	8%	0
There was sufficient time to address the villagers' perceptions of soil fertility.	7%	21%	51%	21%	0

Part 3. Participant's impressions on the distribution of information and the allocation of time.

	CENTURY Modeling			Carbon Measurement		
	Too Much	Adequate	Too Little	Too Much	Adequate	Too Little
Amount of information presented to the participants	0%	93%	7%	0	93%	7%
Amount of work expected of the participants	20%	73%	7%	7%	72%	21%

Landscape Carbon Sampling and Biogeochemical Modeling

Common interest exists between small-scale farmers striving to accumulate and better manage organic resources, and the concerns of global society seeking mitigation to atmospheric change. Too often, environmental and agricultural goals are viewed as incompatible but this need not be the case with carbon sequestration in Africa. A two-week skills development workshop was conducted in Senegal for the purpose of demonstrating and comparing field measurement, remote sensing and simulation modeling as a means of assessing system carbon dynamics. Participants were instructed in both field settings and a computer laboratory on approaches to increasing carbon stocks through land management its likely impact on land managers. The workshop concluded with participants formulating concerning policy options, new collaborative modes and specific technologies with potential to result in carbon sequestration and benefits to Senegalese stakeholders.

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